



National Library
of Canada

Bibliothèque nationale
du Canada

Canadian Theses Service

Service des thèses canadiennes

Ottawa, Canada
K1A 0N4

NOTICE

The quality of this microform is heavily dependent upon the quality of the original thesis submitted for microfilming. Every effort has been made to ensure the highest quality of reproduction possible.

If pages are missing, contact the university which granted the degree.

Some pages may have indistinct print especially if the original pages were typed with a poor typewriter ribbon or if the university sent us an inferior photocopy.

Previously copyrighted materials (journal articles, published tests, etc.) are not filmed.

Reproduction in full or in part of this microform is governed by the Canadian Copyright Act, R.S.C. 1970, c. C-30.

AVIS

La qualité de cette microforme dépend grandement de la qualité de la thèse soumise au microfilmage. Nous avons tout fait pour assurer une qualité supérieure de reproduction.

S'il manque des pages, veuillez communiquer avec l'université qui a conféré le grade.

La qualité d'impression de certaines pages peut laisser à désirer, surtout si les pages originales ont été dactylographiées à l'aide d'un ruban usé ou si l'université nous a fait parvenir une photocopie de qualité inférieure.

Les documents qui font déjà l'objet d'un droit d'auteur (articles de revue, tests publiés, etc.) ne sont pas microfilmés.

La reproduction, même partielle, de cette microforme est soumise à la Loi canadienne sur le droit d'auteur, SRC 1970, c. C-30.

THE UNIVERSITY OF ALBERTA

EFFECT OF ISOPROPYL-N-CHLOROPHENYL CARBAMATE APPLICATION AND
STORAGE VARIABLES ON POTATO CHIP COLOR

by

PIRSHING K. MAHMOOD GUDMUNDSSON

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

IN

HORTICULTURE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1988

Permission has been granted to the National Library of Canada to microfilm this thesis and to lend or sell copies of the film.

The author (copyright owner) has reserved other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without his/her written permission.

L'autorisation a été accordée à la Bibliothèque nationale du Canada de microfilmer cette thèse et de prêter ou de vendre des exemplaires du film.

L'auteur (titulaire du droit d'auteur) se réserve les autres droits de publication; ni la thèse ni de longs extraits de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation écrite.

ISBN 0-315-42812-0

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR PIRSHING K. MAHMOOD GUDMUNDSSON
TITLE OF THESIS EFFECT OF ISOPROPYL-N-CHLOROPHENYL CARBAMATE
APPLICATION AND STORAGE VARIABLES ON POTATO
CHIP COLOR
DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE
YEAR THIS DEGREE GRANTED SPRING, 1988

Permission is hereby granted to THE UNIVERSITY OF ALBERTA LIBRARY
to reproduce single copies of this thesis and to lend or sell such copies for private,
scholarly or scientific research purposes only.

The author reserves other publication rights, and neither the thesis nor extensive
extracts from it may be printed or otherwise reproduced without the author's written
permission.

(SIGNED)

Pirshing

PERMANENT ADDRESS:

Dept. of Plant Science

University of Alberta

Edmonton, Alberta

DATED *April 26* 1988

"Potatoes . . . the world's most versatile food product.

Nature has designed only a few foods that are capable of nourishing the great populations of the world. Of these, the potato is one of the best known. Beneath its skin are liberal stores of not only energy, but of valuable nutrients to support growth and health.

In addition to fresh potatoes, there are many fine processed potato products on the market. Potatoes come in many ways, and can be prepared in many, many more ways."

Valley Potato Grower

January - 1979

THE UNIVERSITY OF ALBERTA
FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled EFFECT OF ISOPROPYL-N-CHLOROPHENYL CARBAMATE APPLICATION AND STORAGE VARIABLES ON POTATO CHIP COLOR submitted by PIRSHING K. MAHMOOD GUDMUNDSSON in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in HORTICULTURE.

Wm. T. Andrew

Supervisor

Lurane G. Myers
Robert L. ...
Edna ...

Date *MARCH 28, 1988*

Dedicated
to
the memory
of my beloved grandparents

ABSTRACT

The potato cultivar 'Norchip' was used in this study to evaluate the effect of isopropyl-N- (3-chlorophenyl) carbamate (C.I.P.C.) application, storage temperature and storage duration on % reducing sugars, sucrose content and chip color.

In this study, it was found that C.I.P.C. did not have a significant effect on % reducing sugars and sucrose content. C.I.P.C. had a significant effect on chip color ($P = 0.014$).

The storage temperature significantly affected the three variables: % reducing sugars, sucrose content and chip color ($P < 0.001$). Within the limits of this study, the highest % reducing sugars and sucrose content and the darkest chip color (lowest scores) were associated with the lowest temperature. The lowest % reducing sugars and sucrose content and the lightest chip color (highest scores) were associated with the highest temperature.

Storage duration exerted a significant effect on % reducing sugars, sucrose content and chip color ($P < 0.001$). Within the limits of this study, the longest storage duration produced the lowest % reducing sugars, the lowest sucrose content and the lightest chip color.

The effect of the C.I.P.C. and temperature interaction was not significant for the three variables: % reducing sugars, sucrose content and chip color.

On the basis of the regression analysis, the sucrose content was affected by the temperature changes first, followed by changes in the reducing sugars. The change in the chip color scores was associated with changes in the % reducing sugars more than with the changes in sucrose content.

There was a significant strong negative correlation between chip color and % reducing sugars. A significant, but less strong, negative correlation existed between chip color and sucrose content. There was also a significant strong positive correlation between chip color and storage duration. All the correlations were significant at $P \leq 0.01$.

ACKNOWLEDGEMENTS

I gratefully acknowledge the help and the support of my husband Vidar throughout the course of this study, especially during the time I was doing the research and laboratory work.

I wish to thank and acknowledge the assistance of the following:

1. Dr. Wm. T. Andrew, my supervisor for his advice, support, guidance and patience during this study and preparation of this thesis.
2. Dr. G. Mazza of Agriculture Canada Research Station, at Morden, Manitoba for providing the thesis topic and his advice.
3. Dr. R.T. Hardin for his advice on the Statistical analysis of the data, and the computing analysis.
4. Dr. R.T. Weingardt for his help in making the tables and the plots.
5. Dr. T. Smyrl for his advice and the use of his laboratory at the Brooks' Research Station to learn specific analytical procedures.
6. Dr. B. Ooraikul for his criticism and support
7. Dr. J.P. Tewari for chairing my final examination
8. Dr. E. Toop for his counselling.
9. Mr. P.F. Arthur for preliminary statistical work and computer advice.
10. Mrs. J. Steinik and Mr. J. Hung of Brooks Laboratory Research Station for providing training for sugar analyses.
11. Mr. D. Karnitz of Old Dutch Potato Chips for providing the raw potatoes, and Mr. D. Wilson of PPG Industries Canada Ltd, Stanchem Division, chemical company for supplying the C.I.P.C.
12. The Zewar family for their help in washing and cleaning the potatoes

Finally, I would like to thank all my friends who supported me during this study especially Mrs. Elsa Marahrens for her encouragement during the writing of this thesis. Special thanks to my husband's family and all my family for their patience and support.

Table of Contents

Chapter	Page
1. INTRODUCTION	1
2. LITERATURE REVIEW	4
2.1 Sprout Inhibitors in Potatoes, Types of Sprout Inhibitors and Methods of Application	4
2.1.1 Sprout inhibitors in potatoes	4
2.1.2 Types of sprout inhibitors	5
2.1.3 Internal Sprouting	5
2.1.4 Applications of sprout inhibitors	7
2.1.4.1 Maleic hydrazide (MH)	7
2.1.4.2 Tetrachloronitrobenzene (TCNB)	8
2.1.4.3 Isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.), chlorpropham or Sprout Nip	8
2.1.4.4 Alcohols	11
2.1.4.5 Methyl-ester of alpha naphthalene acetic acid (MENA)	12
2.1.4.6 Irradiation	12
2.2 Storage Factors	14
2.2.1 Storage temperatures	15
2.2.2 Effect of storage temperature on the sugar level of stored potato tubers	16
2.2.2.1 Storage at high temperatures	16
2.2.2.2 Storage at low temperatures	17
2.2.2.3 Sweetening	17
2.2.2.4 Reconditioning after long term storage	19
2.2.2.5 Effect of storage temperature on processing quality	20
2.2.3 Storage humidity	21
2.3 Processing Discoloration	21
2.3.1 Enzymatic discoloration	22
2.3.2 After-cooking darkening	22

2.3.2.1 Causes of after-cooking darkening	22
2.3.3 Non-enzymatic browning or Maillard reaction	23
3. MATERIAL AND METHODS	24
3.1 Materials	24
3.1.1 The potatoes	24
3.1.2 Sprout inhibitor	24
3.2 Methods	24
3.2.1 Specific gravity	24
3.2.2 Treating potatoes with C.I.P.C.	25
3.2.3 Temperature	26
3.2.4 Duration of storage period	26
3.2.5 Experimental design	26
3.2.6 Analyses	27
3.2.6.1 Reducing sugars analysis	27
3.2.6.2 Sucrose content analysis	30
3.2.6.3 Chip making and chip color scoring	32
4. RESULTS	34
4.1 Storage duration	34
4.2 Sprout inhibitor (C.I.P.C.)	34
4.3 The Storage Temperature	35
4.4 The sprout inhibitor (C.I.P.C.) and temperature interaction	35
4.5 Regression analysis of the three variables on storage duration	35
4.6 Correlation of chip color to other quality parameters and storage duration	38
5. DISCUSSION	56
5.1 The Storage duration	56
5.2 The Sprout inhibitor (C.I.P.C.)	57
5.3 The Storage temperature	58

5.4	The sprout inhibitor (C.I.P.C.) and temperature interaction	58
5.5	Regression analysis of the three variables on storage duration	58
5.6	Correlation of chip color to other quality parameters and storage duration	60
6.	SUMMARY AND CONCLUSIONS	62
7.	LITERATURE CITED	64
8.	APPENDIX TABLES	73
8.1	Appendix 1. Analysis of variance of chip color.	74
8.2	Appendix 2. Analysis of variance of % reducing sugars	75
8.3	Appendix 3. Analysis of variance of sucrose content.	76
8.4	Appendix 4. Treatment means of chip color, % reducing sugars and sucrose content for (C.I.P.C.) and temperature combinations.	77

LIST OF TABLES

Table	Page
1. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for each storage duration	39
2. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for the two levels of C.I.P.C.	40
3. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for the three storage temperatures (6, 9 and 12°C)	41
4. Regression of chip color on storage duration for the three storage temperatures (6, 9 and 12°C) without C.I.P.C. application.....	43
5. Regression of % reducing sugars on storage duration for the three storage temperatures (6, 9 and 12°C) without C.I.P.C. application.	45
6. Regression of sucrose content on storage duration for the three storage temperatures (6, 9 and 12°C) without C.I.P.C. application.	47
7. Regression of chip color on storage duration for C.I.P.C. and temperature combinations.....	49
8. Regression of % reducing sugars on storage duration for C.I.P.C. and temperature combinations.....	51
9. Regression of sucrose content on storage duration for C.I.P.C. and temperature combinations.....	53
10. Correlation of chip color to % reducing sugars, sucrose content and storage duration for C.I.P.C. and temperature combinations:	54

LIST OF FIGURES

Figure		Page
1.	Calibration curve for the reducing sugar(glucose).....	28
2.	Regression of chip color on storage duration for each of the three storage temperatures.	42
3.	Regression of % reducing sugars on storage duration for each of the three storage temperatures.	44
4.	Regression of sucrose content on storage duration for each of the three storage temperatures.	46
5.	Regression of chip color on storage duration for C.I.P.C. and temperature combinations.....	48
6.	Regression of % reducing sugars on storage duration for C.I.P.C. and temperature combinations.....	50
7.	Regression of sucrose content on storage duration for C.I.P.C. and temperature combinations.....	52

1. INTRODUCTION

The potato chip industry in North America relies on potatoes from storage for nearly 7 months (early October to mid-April) during the year. It is important to have a uniform product for the chipping industry to maintain a desirable chipping quality during the storage season. To provide a regular flow of tubers to the processing plant throughout the year, potato tubers must be kept in recommended storage conditions (Work *et al.*, 1981).

The most important factor affecting potato chip quality is the chip color (Smith, 1975; Smith, 1967). The preference of the consumer is for a light brown chip. Color control is necessary to maintain a quality product. The color of the potato chip is determined by the chemical composition of the potato tuber. The chemical composition of the tubers depends upon many environmental factors during growth some controllable, some not, and also upon handling during transit and storage (Smith, 1977).

In addition to environmental factors, potato quality for processing is also affected by cultural factors. The cultural and environmental factors include: 1) date of planting, 2) soil type, 3) soil reaction, 4) soil moisture, 5) season, 6) location, 7) mineral nutrition of the plants, 8) cultivation and weed control, 9) spray program for control of insects and diseases, 10) temperature during the growing season, 11) time and method of killing vines, and 12) time of harvest (Smith, 1967).

High specific gravity or total solids, low reducing sugar content combined with high degree of maturity are factors that contribute to good chipping quality (Habib and Brown, 1956). High specific gravity potatoes yield more potato chips from a given quantity of potatoes (Smith, 1977). High specific gravity also helps to regulate the oil content of the finished chips (Cunningham and Stevenson, 1963), and to some degree the color of the chips (Smith, 1967; Zaehring, 1967).

The components of the tuber that are important for potato chip quality are the sugars. The major sugars are sucrose (disaccharide, a non-reducing sugar), and glucose and fructose (monosaccharides, reducing sugars).

According to Miller *et al.* (1975), the reducing sugar glucose contributes to dark chip color. According to Shallenberger *et al.* (1959), sucrose can also contribute to dark chip color during frying after hydrolyses into glucose and fructose.

During storage at low temperatures, starch converts to sucrose by phosphorylase activity (Shekhar and Iritani, 1978; Hyde and Morrison, 1964) and sucrose converts to the reducing sugars by invertase activity (Carlsson, 1970). The free amino acids react with the reducing sugars resulting in darker colored chips. This reaction is called the non-enzymatic browning or the Maillard reaction (Spark, 1969). Fully mature potatoes are highly desirable for chipping, since they are of higher specific gravity and of lower reducing sugar contents. A good measure of maturity of a tuber at the time of harvest is the sucrose level. One procedure to evaluate the sucrose content, is the sucrose rating (SR), (Sowokinos, 1973). SR can be measured as mg sucrose/g tuber. SR in good potato chippers does not exceed 2.8 mg sucrose/g tuber (Sowokinos, 1978).

Early seed potato planting, late harvesting and slow vine killing results in tubers of higher maturity (Smith, 1975).

Good storage should provide the best conditions to maintain the tubers at their best for processing. The relative humidity should not be lower than 95%. The storage temperature should not be too low to cause sugar accumulation, or too high to cause sprouting and subsequent senescence. Also, high temperatures for long periods result in certain types of potato rots (Rastovski, 1981).

For potatoes stored at low temperatures, before processing, a period of reconditioning is necessary for conversion of the accumulated reducing sugars into starch. The optimum temperature for reconditioning varies with the period of reconditioning (Work *et al.*, 1981). Prolonged storage at high temperatures during reconditioning can result in sprout formation. To solve the problem of sprouting, sprout inhibitors have to be applied on tubers in storage. The most satisfactory sprout inhibitor that is applied during the storage period is isopropyl-N-(3-chlorophenyl) carbamate, or C.I.P.C which is also known as sprout nip or

chlorpropham, (Leach, 1978). Chemical sprout inhibitors used in a storage must be applied after wound healing, i.e., the curing period, otherwise suberization will be inhibited and consequently the tuber will rot (Van Es and Hartmans, 1981).

The objectives of this study were to investigate the responses in the reducing sugars, sucrose content and chip color of 'Norchip' Potatop cultivar as a function of: 1) different storage durations, 2) treatment with and without C.I.P.C. and 3) different storage temperatures. In addition, chipping quality was related to reducing sugars, sucrose content and storage duration.

2. LITERATURE REVIEW

2.1 Sprout Inhibitors in Potatoes, Types of Sprout Inhibitors and Methods of Application

2.1.1 Sprout inhibitors in potatoes

Increased interest in chemical inhibitors for sprouting started during World War II. Chemical sprout inhibitors were suggested as an alternative to refrigeration to keep potatoes sprout free during transportation to all parts of the world. Potato processors who wished to store their produce at 10°C or higher found that this put a limitation on the use of temperature, therefore some method other than temperature manipulation had to be used. This was particularly important for the potato processors who wanted to be able to purchase as large a portion of the raw product as possible at periods of peak supply when prices were low, (Sawyer, 1975). Since 1950, chemical sprout inhibitors have been accepted commercially in the form of, a) dust applied on tubers in storage, b) spray applied to potato foliage in the field, and c) volatile chemicals introduced into the storage. Smith (1977) and Nylund and Ayers (1964) reported that holding potato tubers in paper bags impregnated with C.I.P.C. reduced sprouting.

Chemical inhibitors are only part of a good sprout control program. Manipulation of temperature is also of great importance. However, the cultivar, planting date, and harvest dates will affect the maturity and dormancy of the crop, and these should be utilized in the sprout inhibition program by processors who wish to keep their produce sprout-free for long periods, and in the best possible condition for up to one year (Sawyer, 1975). Sprout inhibitors which inhibit growth of sprouts will also suppress suberization and wound periderm formation. This condition favors bacterial and fungal infections, resulting in rotting of the produce. The potato tubers must therefore be treated with sprout inhibitors after the wound periderm has formed to prevent storage losses due to bacterial and fungal rots (Van Es and Hartmans, 1981).

2.1.2 Types of sprout inhibitors

A number of chemicals have been tested to determine their effect on sprout inhibition. Examples include ethylene, alcohol, abscisic acid, indole acetic acid, and others. The majority of them have not been made use of in a practical way or were used only for a short time.

Two compounds, however, isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.) and maleic hydrazide (MH) have proven to be of practical value. Methyl ester of alpha naphthalene acetic acid (MENA) appears to have potential in this area. Other than chemical agents, considerable research has been done on the irradiation of potato tubers to inhibit sprouting (Van Es and Hartmans, 1981; Smith, 1977; Sawyer, 1975).

The most important consideration in any sprout inhibition program is temperature control. Temperature influences sprouting as well as storage rots, respiration and moisture loss. Sprout growth is very slow at low temperatures of 3°C and 4.5°C. As the temperature increases above 4.5°C, the rate of sprout growth increases; and above 10°C, the increase is more rapid (Sawyer, 1975). In conjunction with temperature and humidity control, sprouting can be decreased by the use of chemical inhibitors (Van Es and Hartmans, 1981; Sawyer, 1975). For potato processors who wish to get the longest storage life and the best fried product, the temperature should be held low, considering chip color (Sawyer, 1975).

At present, only three chemical sprout inhibitors are permitted for use by the Environmental Protection Agency, which are maleic hydrazide (MH), tetrachloronitrobenzene (TCNB) and isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.). The Food and Drug Administration allows the use of irradiation to inhibit potato sprouting (Anonymous, 1985).

2.1.3 Internal Sprouting

Internal sprouting of potatoes has been considered a problem in commercial storages for many years. Sawyer reported (1961) that there is no evidence that C.I.P.C. is the cause of internal sprouting, and he stated that the problem of internal sprouting is not linked with C.I.P.C. or any other inhibitor, but C.I.P.C. at marginal dosages (low levels) may accentuate

the problem when the stored potatoes are old. Conditions such as high storage temperatures and low humidity accentuate aging of the potatoes in the storage. According to Davis (1961), conditions leading to internal sprout growth include agents which injure and destroy the apical meristem or the dominance of the apical meristem of exposed sprouts, without inhibiting their expansion and development completely. Such agents include light, brief freezing, and volatile chemical compounds.

Internal sprouting has been reported in treatments involving many sprout inhibitors including C.I.P.C. and MH; in table stock, seed, and chipping potatoes. Sawyer and Dallyn (1964) reported in their research that even marginal doses of C.I.P.C. did not enhance internal sprouting; and increased dosages of C.I.P.C. decreased internal sprouting. In their research, the control with no sprout inhibitor had the highest level of internal sprouting. According to Sawyer and Dallyn (1964), the most important factor involved in internal sprouting was high storage temperature. Internal sprouting appears to be mechanically triggered. When there is a line of least resistance for a sprout growth to grow through a tuber, there is internal sprouting.

Hruschka *et al.* (1965) reported that potato tubers stored for five months at 16°C and 85% relative humidity, developed internal sprouts. External sprouts were partially suppressed when the tubers were 1) treated with trace levels of C.I.P.C. as a smoke or aerosol, 2) when tubers were stored close to tubers that were treated with C.I.P.C. aerosol or dip, and 3) when stored near other fruits or vegetables in buildings containing volatile chemicals. By increasing the concentration of C.I.P.C. above trace levels and applying it as smoke aerosol, the amount of both external and internal sprouting was reduced. At 18°C, the potatoes developed external and internal sprouts, however, below 12°C only few sprouts developed. Application of C.I.P.C. before or after the external sprouts have started had no significant effect on number of tubers with internal sprout growth. Tubers Dipped in a C.I.P.C. emulsion of 5,000 ppm (0.5%) did not develop external or internal sprouts (Khurana and Randhawa, 1985; Khurana *et al.*, 1985; Hruschka, *et al.*, 1965). Hruschka and Heinze (1967) reported that dipping

potato tubers (Irish cobbler) in 1,000 ppm (0.1%) C.I.P.C. gives a high degree of control on both external and internal sprouts, but this control was not found to be consistent from year to year.

2.1.4 Applications of sprout inhibitors

The commercially accepted sprout inhibitors and those which have appeared most promising in research programs are classified and discussed below as to time of application and method of application.

2.1.4.1 Maleic hydrazide (MH)

The greatest use of this sprout inhibitor has been for potato processors who plan to hold potato tubers for long periods, and for potatoes to be processed into chips (Anonymous, 1985; Sawyer, 1975). Maleic hydrazide is best sprayed on the vines in the field 2 to 3 weeks after full bloom (Anonymous, 1985) or 4 to 6 weeks before harvest (Franklin and Thompson, 1953; Kennedy and Smith 1953). At this stage of growth, the foliage is green with few or any yellow leaves and sufficient material will be translocated from the foliage to the tubers. If maleic hydrazide is applied at a later stage, i.e., when the leaves start to turn yellow, an adequate amount of the chemical may not be absorbed to control sprouting (Anonymous, 1985). If the application is carried out too early in the season, it results in a heavy set of tubers with few tubers reaching marketable size and shape (Van Es and Hartmans, 1981; Sawyer, 1975).

According to Weis *et al.* (1980), in a 3 year study in central Wisconsin, a foliar application of maleic hydrazide on Russet Burbank during early to mid-July resulted in an increase in the yield of U.S. number 1 tubers. When applications were made in mid and late July, the best sprout control in storage was obtained. Applications at any time during early July and early August resulted in more desirably shaped and marketable potatoes. Applications during early June, resulted in a severe decrease in yield and increased incidence of mis-shapen tubers.

Three pounds of maleic hydrazide per acre (3.36 kg/ha) is effective in retarding sprouting (Weis *et al.*, 1980; Sawyer, 1975; Bishop and Schweers, 1961). Potatoes that had been treated with maleic hydrazide and stored at 7.3°C did not show a change in color after frying and the sugar level was not changed, in comparison to untreated tubers (Zaehringer *et al.*, 1966).

Maleic hydrazide application is very limited in Europe but is widely accepted in the United States and Canada (Van Es and Hartmans, 1981).

2.1.4.2 Tetrachloronitrobenzene (TCNB)

Tetrachloronitrobenzene is used commercially in some European countries, Australia and the United States. This inhibitor is marketed in the United States under the trade name Fusarex. It has fungicidal properties (Sawyer, 1975). Reports indicate that TCNB is a relatively weak sprout inhibitor, therefore, it has been used as a sprout suppressant on seed potatoes (Anonymous, 1985; Dalziel *et al.*, 1980; Sawyer, 1975). TCNB is also widely used to control sprouting in potatoes stored at 7°C or above for use in potato processing (Filmer and Rhodes, 1984). The application of TCNB is made when potatoes are placed in storage (Anonymous, 1985; Filmer and Rhodes, 1984). TCNB is applied as a dust (Filmer and Rhodes, 1984; Dalziel *et al.*, 1980; Sawyer, 1975). It is available in the United States as a 6% dust and is used at a dosage of 1 lb/600 lb of tubers (Sawyer, 1975), or at a rate of 135 mg/kg of tubers (Filmer and Rhodes, 1984). The dust occasionally has caused discoloration problems on table stock tubers. This would not affect tubers for processing or table stock tubers washed after storage and before marketing (Sawyer, 1975).

2.1.4.3 Isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.), chlorpropham or Sprout Nip

Isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.) is the most widely used sprout inhibitor commercially in the United States and Canada (Ponnampalam and

Mondy, 1986; Filmer and Rhodes, 1984; Corsini *et al.*, 1979; Sawyer, 1975) and in the Netherlands (Buitelaar, 1981; Kim *et al.*, 1972). A closely related compound, isopropyl-N-phenyl carbamate (IPC) or propham is used in Australia and some European countries. C.I.P.C. is the strongest chemical found in the sprout inhibition field (Sawyer, 1975).

C.I.P.C. inhibits protein synthesis and mitosis. It inhibits root and shoot growth and it inhibits the protolytic activity of the chloroplast, (Wilson *et al.*, 1981). Ivens and Blackman (1949) studied the effect of ethyl phenylcarbamate, a related compound to C.I.P.C. on mitosis in roots. They proposed that the carbamate esters combine with the lipid compound of the spindle protein causing intramolecular precipitation, collapse and disintegration of the spindle. Because of this antimitotic effect of the carbamate group, C.I.P.C. must be applied to potatoes in storage subsequent to wound healing or periderm formation, (Anonymous, 1985; Leach 1978; Smith 1977; Sawyer 1975; Sawyer 1961).

The minimum concentration of C.I.P.C. required to inhibit sprouting completely is estimated to be 20 ppm by Corsini *et al.*, (1979).

According to Reeve *et al.*, (1963), an application of 1 ppm will completely prevent suberization, and Kim *et al.* (1972) found that a sprout growth in the form of a rosette can develop following the application of low levels of C.I.P.C.. Tubers should be free from soil before the chemical is applied, otherwise it is prevented from contacting the eyes, in which case the tubers will sprout later during storage period. Van Vliet and Sparenberg (1970) found good results when they applied C.I.P.C. by three different methods, as a dust, as a fog through a fogging device and in a porous cartridge placed in the airduct.

A disadvantage of applying C.I.P.C. as a gas or fumigant through the air distribution system is uneven distribution of C.I.P.C. concentration through the pile. Tubers on the top layer have high concentration of C.I.P.C. immediately after application, which decreases after a short time (Anonymous, 1985). Therefore, even

distribution is a necessary factor when applying C.I.P.C. in any form, or using any method (Smith, 1977; Sawyer, 1975).

Nylund and Ayres (1964) reported that using C.I.P.C.-treated paper bags reduced weight loss due to sprouting. Total shrinkage also was reduced in tubers held in treated paper bags.

C.I.P.C. can be applied in the form of a powder or liquid. Powders are available in different degrees of fineness or different colors to satisfy the different ways of application. For example fine powders are used for blowing, whereas coarser powders are used for dusting. Different colors of powders are used for treating different potato skin colors. For satisfactory results, it is necessary to apply the compound at the correct time with accurate distribution. Powders used for large scale applications may contain 10 g of the active ingredient per kg of compound per tonne of potatoes in potato storages. Only one treatment per lot is recommended when the sprout suppressant is in the form of a dust, (Buitelaar, 1981).

A combination of fungicide (thiabendazole), chlorpropham and propham in the amounts of 20 g, 7.4 g and 2.5 g, respectively, per kg of powder substance can be used to control dry rot in storage.

The advantage of applying C.I.P.C. in the form of dust is that a single application is enough. The disadvantages, however, are 1) skin irritation at times when the potatoes are still not suberized sufficiently, 2) loss of some of the natural color of the potato skin and, 3) the dust nuisance is left after the storage is emptied, (Buitelaar, 1981).

C.I.P.C. in the form of liquid can be atomized with special equipment and distributed throughout the potatoes in the storage by means of the internal ventilation system. Fans are shut off immediately after treatment for 24 to 48 hours, (Sawyer, 1975). Since the effect of residues of C.I.P.C. in the form of liquid is smaller, more active substance may be used. The maximum being 20 g of active ingredient per tonne of

potatoes. The total permissible volume, may be applied one, two, or three times (treatments) as required. It is advisable that the first dose can be increased if the sprouting potential of the potatoes is high. The subsequent doses of later treatments may be reduced correspondingly, (Buitelaar, 1981).

Disadvantages of applying C.I.P.C. in the liquid form are, 1) condensation of the compound on the ventilation system fan, and 2) the date of the first application is sometimes overlooked. The advantages of applying C.I.P.C. in the liquid form are numerous, for example, 1) when the sprout inhibitor is applied early (two or three weeks after harvest), as in case of early delivery of the potatoes, less amount is used, 2) there is no dust nuisance, 3) the skin color of the potatoes looks more natural, and 4) less irritation of the tuber skin, since the skin has already set by the time of the first application (Buitelaar, 1981).

The cost of sprout inhibitors, in comparison to the cost of potatoes is negligible. Whether liquids or powders are applied, the cost is the same, but since the liquid is more commonly used, the cost of its application is more expensive, particularly because a number of treatments are required in the liquid form.

2.1.4.4 Alcohols

Several of the alcohols have been used commercially on a small scale in England, Denmark and the Netherlands for control of sprout growth in storage. For example, vapors of nonyl or amyl alcohols, at concentrations ranging from 0.05 to 0.12 mg per litre of ventilating air have been used (Van Vliet and Schriemer, 1963; Sawyer and Thorne, 1962).

Decyl alcohols compare with C.I.P.C. in controlling shrinkage factors. The decyl alcohols have no effect on chipping and do not tend to give after-cooking darkening (Sawyer and Thorne, 1962). These materials have no federal clearance for use in the United States or Canada (Sawyer, 1975).

2.1.4.5 Methyl-ester of alpha naphthalene acetic acid (MENA)

This chemical inhibitor has been tested in several countries including the United States. Serious storage losses were encountered when this material was used as a dust, due to its effects on wound healing. An application of 1.66 g per 100 lbs of tubers, applied as a dust or liquid, is more effective than TCNB. This concentration of MENA as a gas application does not have any effect on wound healing if applied at the right time. MENA has been applied in the form of wax emulsion or a water solution when tubers are washed at the time they are removed from storage (Sawyer, 1975). Meigh *et al.* (1973) found that MENA occurs naturally in the storage atmosphere and it does exhibit a sprout suppressant effect.

2.1.4.6 Irradiation

Irradiation has been proved to be a potent sprout inhibitor in the United States and Canada (Anonymous, 1985; Sawyer, 1975), and in Europe, especially in the Netherlands (Buitelaar, 1981). The inhibitory effect of irradiation on potato sprouts surpasses that of chemical sprout inhibitors (Buitelaar, 1981; Sawyer and Dallyn, 1961, Burton and Hannan, 1957).

The control of sprouting commercially can be achieved with most potato cultivars using doses between 5,000 and 10,000 REP. Within this range of dosage, the effect of irradiation on various darkening reactions and potato storage rots is minimized (Sawyer, 1975). Cotter and Sawyer (1961), reported that irradiation increases black spot in potato tubers. A dosage of 10,000 r was not enough to increase the black spot. The response varies from year to year and it is cultivar specific. High levels of ascorbic acid in a particular cultivar results in natural-radio resistance and irradiation treatment decreases the ascorbic acid content of the tubers.

According to Sawyer and Dallyn (1961), commercial sprout control for long storage period, can be achieved with radiation doses of 7,500 to 12,500 r. Irradiation at 12,500 r caused a reduction in wound healing and normal periderm formation.

The irradiation of potato tubers has a number of undesirable side effects, for example: 1) increased fusarium attack, 2) grey discoloration of potatoes after cooking, 3) increased reducing sugar content, 4) grey discoloration of prefried french fries and, 5) darker chip colors, (Buitelaar, 1981). The irradiation treatment leaves no residues, as do chemical sprout inhibitors. The costs of the irradiation treatment is much higher than the cost of using chemical sprout inhibitors which makes it economically noncompetitive with the chemicals available. Therefore, there is little use for this sprout inhibition technique and the chance for practical application of irradiation appears to be slight (Buitelaar, 1981; Sawyer, 1975).

Generally speaking, there should not be any form of application of any type of sprout inhibitor unless there is a need for it. In some years, the rest period and cool storage temperatures are enough to keep potato tubers sprout-free for the normal storage period (Sawyer, 1975).

The use of temperature to control sprouting is very important. Since potatoes do not sprout at temperatures of 4°C or below, they should be cooled with outside air in countries where the outdoor air temperatures falls to 4°C or below, otherwise mechanical refrigeration should be used. Cold storage at 4°C or below has disadvantages, for example: 1) accumulation of reducing sugars which causes sweetening of the potatoes and later produces dark chips, which is a major concern for potato chippers; 2) when it is necessary to store potatoes for longer periods, i.e., after the outside air temperature warms to above 4°C, expensive mechanical refrigeration will be required; 3) ventilation requires attention and, 4) the potatoes will quickly sprout (if they have been in extended storage) after they have been allowed to warm up prior to delivery, (Buitelaar, 1981).

2.2 Storage Factors

Due to climatic conditions prevailing in temperate and subarctic growing areas, potatoes have to be planted and harvested at certain times of the year. Since there is only one potato growing season available in such environments, the potatoes have to be stored to supply the demand for the rest of the year (Schild, 1981).

Potato tuber is a living organism, containing approximately 80% water. Its cork-like skin contains small pores (lenticels) which permits gas exchange and evaporation to occur. The potato tuber can commonly be stored for several months, until sprout growth, wilting and/or changes in composition terminate storage suitability (Bishop and Maunder, 1980).

The objective of any storage system is to maintain potato tubers in the best condition for table stock, seed or, processing. Another purpose of potato storage is to keep storage losses at minimum and to prolong the storage life of the tubers (Booth and Shaw, 1981; Bishop and Maunder, 1980; Thornton and Sieczka, 1980; Smith, 1977).

Preharvest factors such as physical and physiological condition of the tuber, cultural practices and growing conditions all affect tubers after harvest. Postharvest losses may reduce either quantity or quality or both. Such losses can be reduced by various physical, chemical and biological means in the storage (Booth and Shaw, 1981; Rastovski, 1981).

Potatoes put into storage must be sound, mature, dry and free of soil. Sanitation of the storage must be considered so as to reduce the source of inoculum of pathogens (Booth and Shaw, 1981). The storage period can be divided into three main periods, the curing period (suberization and maturing), the holding period, and the warming period, (Thornton and Sieczka, 1980). Curing involves suberization of bruised cells followed by the formation of a corky layer (wound periderm). The corky layer becomes a barrier against entry of pathogens. During the curing process, general strengthening of the skin of immature tubers also occurs, (Meijers, 1981; Booth and Shaw, 1981, Thornton and Sieczka, 1980). The curing process occurs at temperatures of 12 to 18°C at 85% relative humidity for a period of 7 to 15 days in the presence of oxygen, and this must be done immediately after harvest (Booth and Shaw,

1981). According to Thornton and Sieczka (1980), temperatures of 10 to 15.6°C and a relative humidity above 95% are used for a period of several weeks to effect the curing process.

According to Meijers (1981), the curing process can occur at low temperatures, but at a slower rate. For example, partial curing occurs at 2.5 and 5°C for one or two weeks. Complete curing occurs at 5°C for six weeks. Complete curing takes place at 10°C in two weeks, at a relative humidity of 80 to 100%. The formation of the wound periderm is delayed at both low and very high temperatures.

The holding period is the period of longest storage. The temperature of the holding period depends on the ultimate use of the potato. Temperatures of 4.4 to 10°C are generally used, with 4.4°C for potatoes for fresh market, 7.3°C for potatoes for french fries and 10°C for potatoes for chips. Holding period temperatures are used in conjunction with high relative humidities, (Thornton and Sieczka, 1980).

The warming period is generally used for potatoes that have been held at low storage temperatures. Tubers should be warmed to approximately 10°C for several days, to reduce the amount of reducing sugars (Thornton and Sieczka, 1980). If tubers are held at higher temperatures for extended length of time, sprouting may occur.

2.2.1 Storage temperatures

It is not easy to specify optimum storage temperatures in general terms. However, after potato tubers are cured, a decision should be made about reducing the storage temperature to the required holding temperature. Choice of a holding temperature is influenced by the ultimate use of the tubers, duration of the storage period and the cultivar involved (Rastovski, 1981).

The ranges of common holding temperatures are shown as follows (Booth and Shaw, 1981):

Temperature (°C)	Ultimate Use	Storing Duration
8 - 10	consumer	short term
4 - 7	consumer	long term
10	processing	short term
7 - 8	processing	long term
8 - 12	seed	short term
2 - 4	seed	long term
10 - 20	curing	
14 - 24	reconditioning	

The ranges of common holding temperatures according to Rastovski (1981):

Temperature (°C)	Ultimate Use of Potatoes
5 - 6	fresh consumption
7 - 10	chipping
6 - 8	french frying
2 - 4	seed
7	granulation

2.2.2 Effect of storage temperature on the sugar level of stored potato tubers

2.2.2.1 Storage at high temperatures

Total sugar content increases at temperatures of 24°C and above. When tubers are stored at low temperatures (e.g. 3°C), the increase in total sugar is greater than the increases at higher temperatures. When tubers are transferred to high temperatures, the total sugar content increases sharply, then falls back to the original level. At higher temperatures, the increase in the reducing sugar content, is only slight at first, compared to the increases in cold storage conditions, (Verma *et al.*, 1974a, 1974b).

Potatoes can be stored for up to 4 months at 20°C with the application of C.I.P.C. (sprout suppressant) and a fungicide (thiabendazole) with limited loss. This applies to potato tubers that are not fully mature or sufficiently hardened, provided that suberization and wound healing had taken place (Buitelaar, 1981).

2.2.2.2 Storage at low temperatures

Ohad, *et al.* (1971) found that storing potato tubers at low temperatures, damaged the amyloplast membranes surrounding the starch grains. When tubers are stored at low temperatures, the resulting increased level of sugar could be reversed by the process of reconditioning, though not to the original level. According to Burton (1965), both reducing sugars (glucose and fructose) and non-reducing sugar (sucrose) are increasing below 10°C. Inorganic phosphorus and high sugar levels were found in tubers stored at low temperatures, (Shekhar and Iritani, 1978). Therefore, they suggested that there may be a relationship between inorganic phosphorus and enzymatic activity in the interconversion of starch to sugar in potato tubers.

Mature and immature potatoes respond differently with regard of sugar content to changes in temperature in the storage. According to Isherwood (1976), in mature tubers, when the temperature is raised from 2 to 10°C, the reducing and non-reducing sugars respond differently. For example, the reducing sugars decline gradually while the non-reducing sugar (sucrose) declines fairly sharply.

In immature tubers, the level of reducing sugars are much higher than that of sucrose. When the temperature is raised from 2 to 10°C, both types of sugars (reducing and non-reducing) respond in an identical manner. Isherwood (1976) concluded that this indicates that sucrose and (glucose and fructose) in mature tubers occur in separate cell compartments. In immature tubers, the response manner of sugars to temperature change does not indicate so.

2.2.2.3 Sweetening

a. Senescence sweetening

Sweetening due to senescence once occurred is irreversible and reconditioning may help, (Isherwood, 1976). Sweetening is characterized by changes in the membranes surrounding the starch grain. Senescent sweetening occurs at high temperatures for extended periods of storage or at low

temperatures. When the starch breaks down and the membranes surrounding the starch grain separate and disintegrate, glucose and fructose enter the cell sap, and this contributes to sweetening of the potato tubers, (Isherwood and Burton, 1975). The rate and extent of this sweetening is cultivar specific.

A possible connection also speculated between senescent sweetening and sprout potential, the greater the sprouting potential, the greater the sugar formation. To counteract or delay senescent sweetening is to store potatoes at lower temperatures.

b. Low temperature sweetening

Isherwood (1973, 1976) reported that starch was converted to sugar when mature tubers were stored at 2°C and that sucrose was the first product. Sucrose contributes to the increase in reducing sugar levels to a great extent.

Pressey (1969) indicated that exposing mature potato tubers with low levels of reducing sugars and low concentration of invertase enzyme to 4.4°C, a rapid increase in the enzyme activity, invertase concentration and reducing sugars were observed. Pressey's data indicated that the enzyme invertase is involved in the formation of glucose and fructose from sucrose when potatoes are stored in low temperatures.

c. Sugar changes due to sprouting and sprout suppression

Mobilization and transport of carbohydrates occurs during sprouting, and the transported sugar is sucrose. It was speculated that if the demands of the sprout growth falls below the rate of mobilization, then the carbohydrates accumulates and give rise to sweetening, (Burton, 1977). When sprout suppressants are applied such as C.I.P.C. and gamma irradiation, the mobilized carbohydrates accumulated to a greater extent because of lack of demand by sprout growth and accompanying enhanced respiration, (Burton, 1975, 1977; Van Vliet and Schriemer, 1963).

Isherwood and Burton (1975) reported that an increase in the glucose and fructose contents from less than 1 mg to 3 mg and 5 mg occurred respectively in a group of untreated tubers stored for 17 weeks. The increase of glucose and fructose levels in the treated tubers with C.I.P.C. were smaller.

Burton (1975) stated that the later in the season the potatoes are irradiated to control sprouting, the more the reducing sugars are likely to increase.

2.2.2.4 Reconditioning after long term storage

The aim of reconditioning is to lower the high reducing sugar content which has become too high subsequent to low temperature storage. This process is done by increasing storage temperatures to 15.5°C to 21.1°C for 3 weeks to a month (Iritani and Weller, 1978). During reconditioning, approximately 80% of the reducing sugar is converted into starch, and the remaining 20% is lost through respiration (Van Es and Hartmans, 1981).

Burton (1975) reported that potatoes stored constantly at 10°C has less sugar content than potatoes that were stored first in cold storage for four weeks, then kept for 3 months at 10°C. Only sugars formed by storing potatoes in cold storage can be reconditioned, and sugars arising because of senesced tubers cannot be reconditioned (Iritani and Weller, 1978; Isherwood, 1976). Mature tubers are easier to recondition than immature tubers (Yamaguchi, 1959). For best results, it is good to find the exact time at which sprouting, respiration and senescence are in optimum balance (Van Es and Hartmans, 1981). However, storing potato at temperatures vary daily from 2°C to 10°C can limit sugar formation, but the cost of repeated cooling and moisture loss due to cooling were higher than the benefits of its practical application (Burton, 1969).

2.2.2.5 Effect of storage temperature on processing quality

It has been stated by Rastovski (1981), that storage temperature is the main important factor affecting the quality of potatoes in the storage. Temperatures above 30°C or below 0°C may damage the potatoes. At higher temperatures, storage losses are generally higher. However, the optimum storage temperature depends on the quality of the potatoes upon loading, and also on the end use of storing and duration of the storage. The optimum temperature for long-term storage ranges from 3°C to 10°C. Subsequent to loading into storage, it is desirable to stimulate curing of the potatoes by providing an optimum temperature of 10°C to 20°C, and humidity should be kept at 90 to 95%. After the curing period, the storage temperature should be maintained by proper ventillation.

The accumulation of reducing sugars during storage is of major concern to potato processors. During storage and prior to processing, the extent of biochemical changes occurring provides a major quality factor responsible for the discoloration of the finished product. The result of the interaction of the reducing sugars (glucose and fructose); and the free amino acids produced a brown colored chip/fried potato. Generally, the reducing sugar level is the limiting factor for this discoloration (Smith, 1975; Burton, 1969). Sucrose which serves as a substrate for reducing sugar production may result from factors such as immaturity and physiological stress during growth or storage (Sowokinos, 1973).

In an experiment by Mazza *et al.* (1983) changes in sucrose, reducing sugars, and chip color were studied as a function of temperature. Three potato cultivars grown and stored commercially in Alberta were Kennebec and Norchip, both potato chippers, and Russet Burbank, a french fry cultivar. Isopropyl-N-(3-chlorophenyl)-carbamate C.I.P.C. was applied to tubers in the storage to prevent sprouting.

Tubers were kept initially in a commercial storage at 15°C to suberize, then the Kennebec and Norchip tubers were stored at 10°C and tubers of Russet Burbank at 7°C. Analyses were performed monthly for sucrose, reducing sugar content and chip color.

The chip color of all the cultivars were dark in immature tubers, but improved with tuber maturity until it reached a maximum quality at the final harvest. The chip color turned darker during the initial storage period. The Norchip cultivar provided acceptable chip color throughout the nine months of storage at 10°C. Kennebec did not provide an acceptable chip color but the chip color was better than that of Russet Burbank. Chip color improved generally during the prolonged storage period since sucrose and reducing sugar content declined. Later in the storage period, sucrose and reducing sugar contents started to rise, which indicated the onset of senescent sweetening. Since the tubers were treated with C.I.P.C. and no sprouts were formed, the increase in the sugar levels was not due to sprout formation.

2.2.3 Storage humidity

The relative humidity of the storage must be kept as high as possible, particularly during the curing period. The optimum relative humidity of the storage atmosphere is 95% or more (Rastovski, 1981; Smith, 1975). The lower the humidity the longer the tuber remains without sprouting, but the risk of tuber shrinkage is greater due to water loss (Smith, 1975).

2.3 Processing Discoloration

Commonly, there are three types of discoloration recognized in potatoes being processed.

1. Enzymatic discoloration of peeled or cut raw potatoes.
2. After-cooking darkening.
3. The non-enzymatic browning reaction which usually takes place at high temperatures during processing of potatoes.

2.3.1 Enzymatic discoloration

Enzymatic discoloration occurs in peeled or cut raw potatoes as a result of enzymatic oxidation in the injured cells being exposed to air. Enzymatic discoloration is of commercial importance mainly to the pre-peeling potato industry (Smith, 1977).

It is generally agreed that the major enzyme system responsible for the discoloration of potatoes after injury is polyphenol oxidase. Chlorogenic acid is also partly involved in the enzymatic browning of injured potato tissue. Adding ascorbic acid reduces the ability of the enzyme system to oxidize the substrate catechol, since ascorbic acid seems to scavenge oxygen.

Matured tubers have a slightly lower phenolic content than immature tubers (Mondy *et al.*, 1960). As the storage temperature decreases, the phenolic content increases, therefore low temperatures account for greater discoloration (Mondy *et al.*, 1966b). The higher the specific gravity, the higher the phenolic content of the tubers (Mondy *et al.*, 1966a).

2.3.2 After-cooking darkening

This phenomena occurs in potatoes after cooking. The darkening appears first under the skin at the stem end, and decreases in intensity toward the apical end. This kind of discoloration is noticeable in canned, prepeeled, oil blanched, french fries, potato salads and reconstituted dehydrated products (Smith, 1977).

2.3.2.1 Causes of after-cooking darkening

The occurrence of this undesirable characteristic is due to the formation of a dark colored complex by the reaction of ferric iron and an orthodihydric phenol, probably chlorogenic acid. After cooking, darkening occurs in areas of the potato where iron is concentrated. Treatments with citrate decreases the degree of discoloration of boiled tubers. But, treatments with sodium acid pyrophosphate, completely prevents this discoloration (Smith, 1977). It has been shown that darkening of tubers is more noticeable from plants that are heavily fertilized with nitrogen, and also the tubers contain more orthodiphenols.



2.3.3 Non-enzymatic browning or Maillard reaction

The Maillard browning reaction involves the interaction of amino compounds and reducing sugars during processing of potatoes. It is considered the most important browning reaction since it affects the quality of many processed food to a great extent (De Man, 1980). Sucrose did not yield detectable browning with any amino acid indicating that sucrose was not the cause of the browning (Ashoor and Zent, 1984).

The results of Marquez and Anon's study (1986) showed the participation of both reducing sugars and amino acids on color development of potato chips during frying. Since the free amino acids content did not vary significantly with storage time or storage temperature, it was concluded that the reducing sugars are the limiting factor during color development. Dahlenburg (1982) also indicated that the primary cause of darkening of fried potato slices is the reducing sugar content of the tuber.

3. MATERIAL AND METHODS

3.1 Materials

3.1.1 The potatoes

The potato tubers used in this study were 'Norchip' cultivar grown commercially in southern Alberta under recommended production practices. Harvesting was from September through October. The harvested tubers had been subjected to a curing period, then stored at 40°F (4.4°C) in a commercial storage unit with 98% relative humidity.

Upon arrival at the University of Alberta, Department of Plant Science, the tubers were washed with water, dried with paper towel and stored at 40°F (4.4°C) at 95 to 98% relative humidity until the experiment started. Specific gravity and dry matter content of the tubers were measured. During the experiment, tubers were analysed for reducing sugars and sucrose content, and chip color was measured.

3.1.2 Sprout inhibitor

The sprout inhibitor used in this study was isopropyl-N-(3-chlorophenyl) carbamate (C.I.P.C.). The C.I.P.C. treatment used was the dipping method in which 1 L of C.I.P.C. (350 g/L) was mixed with 17 L of water at room temperature (20-21°C) to make a 2% concentration. This concentration was twice the concentration recommended for spraying, (Wilson, D. 1985).

3.2 Methods

3.2.1 Specific gravity

Specific gravity was determined by weighing the tubers in air and in water. The specific gravity was calculated from the following formula:

sp. gr. = specific gravity

$$\text{sp. gr.} = \frac{\text{weight of tubers in air}}{\text{weight of tubers in air} - \text{weight of tubers in water}}$$

The percentage dry matter content was calculated using the conversion table for specific gravity of potato tubers which is calculated from Von Scheele equation:

$$\text{percent dry matter} = 24.182 + 211.04 (\text{sp. gr.} - 1.0988), (\text{Burton, 1966}).$$

3.2.2 Treating potatoes with C.I.P.C.

Tubers that were to be treated with C.I.P.C. were taken from the cooler, weighed, placed in a metal basket with a flexible handle and lowered into the bucket of prepared C.I.P.C. solution. The dipping time was 90 seconds, the tubers were completely covered by the C.I.P.C. solution during the dipping process. Subsequent to dipping, the tubers were taken out and placed on a two layer paper towel. The treated tubers were then placed in a labelled polyethylene plastic sac sealed with a heat sealer immediately, and stored in one of the storage units for a specific time.

The tubers remained sealed in the polyethylene plastic sacs for 24 hours in the designated storage, and then were transferred from the polyethylene plastic sacs into labelled, onion mesh bags. The onion mesh bags and their contents remained inside each specific storage for the designated storage time for each specific treatment.

The tubers that were not treated with C.I.P.C. were weighed and sealed inside the same type of polyethylene plastic sacs, and underwent the same procedure as the treated tubers.

Treated and untreated tubers that were to be stored at the same temperature inside the same storage were kept separated on different shelves, on opposite sides of the storage unit.

3.2.3 Temperature

The three storage units used for this study were thoroughly washed and cleaned prior to the experiment. Each storage unit was set for a certain (specific) temperature, and the temperatures were 6°C (5-7), 9°C (8-10), and 12°C (11-13). A fan provided ventilation in each storage, and temperatures were recorded continually on seven day charts. Each week a new chart recorder was set to monitor the temperatures and the temperatures were constant within each range for the entire experiment.

3.2.4 Duration of storage period

Storage treatments varied from one week to ten weeks. At the end of each storage period analyses were performed.

3.2.5 Experimental design

The experiment was set up to be a split-plot design. Because of the planned arrangement of the experimental units at the time of the laboratory measurements, the storage duration formed the whole plots, with replicates nested within duration as the whole plot error. The temperature and C.I.P.C. formed the sub plots. The experiment included storage duration (D = one to ten weeks), storage temperature (T = three different storage temperatures; 6, 9 and 12°C), and the sprout inhibitor, C.I.P.C. (two levels; C_1 = no treatment, C_2 = treatment of tubers with 2% C.I.P.C.). There were three replicates (R) for each treatment.

In this study, the effects of the main factors on the three variables, % reducing sugars, sucrose content and chip color were investigated. The main factors were: 1) storage duration, 2) C.I.P.C. treatment and 3) storage temperature. Analysis of variance was applied to test the significance of the effect of the main factors on the three variables. Regression polynomial analysis was applied to study the effect of the storage duration on % reducing sugars, sucrose content and chip color for the three temperatures (6, 9 and 12°C) without

C.I.P.C. treatment, then with and without C.I.P.C. treatment together. Correlations between chip color and % reducing sugars, chip color and sucrose content as well as between chip color and storage duration at each temperature and C.I.P.C. combinations were also investigated in this study.

The treatment combinations of C.I.P.C. and temperatures were completely randomized. The storage durations were successively arranged, starting with longest storage duration and extending through to the shortest storage duration.

3.2.6 Analyses

The analyses were done for reducing sugars and sucrose content, and chip color was scored.

3.2.6.1 Reducing sugars analysis

Preparation of the reagents used for measuring the reducing sugars were as follows:

- a. Dinitrosalicylate reagent - Twenty grams of 3,5-dinitrosalicylic acid was suspended in 400 ml of distilled water in a 4 L beaker. A solution of 32.0 g of sodium hydroxide that had been dissolved in 320 ml distilled water was then added slowly. Then 600 g of potassium sodium tartrate was gradually added to the combined solution. Heat and stirring were applied until dissolving was complete. The reagent was diluted to 2000 mls with distilled water, kept in a dark bottle and stored in the dark.
- b. Standard glucose solution - The standard glucose solution was prepared by dissolving 5 g of anhydrous glucose in 500 ml distilled water. One millilitre of this solution is equivalent to 10 mg of glucose.

A standard curve (Figure 1) was prepared as follows: To a series of dry, clean, chilled 100 ml volumetric flasks, 1, 3, 5, 10, 20 and 30 ml of the standard glucose solution were added. The contents of each volumetric flask was then

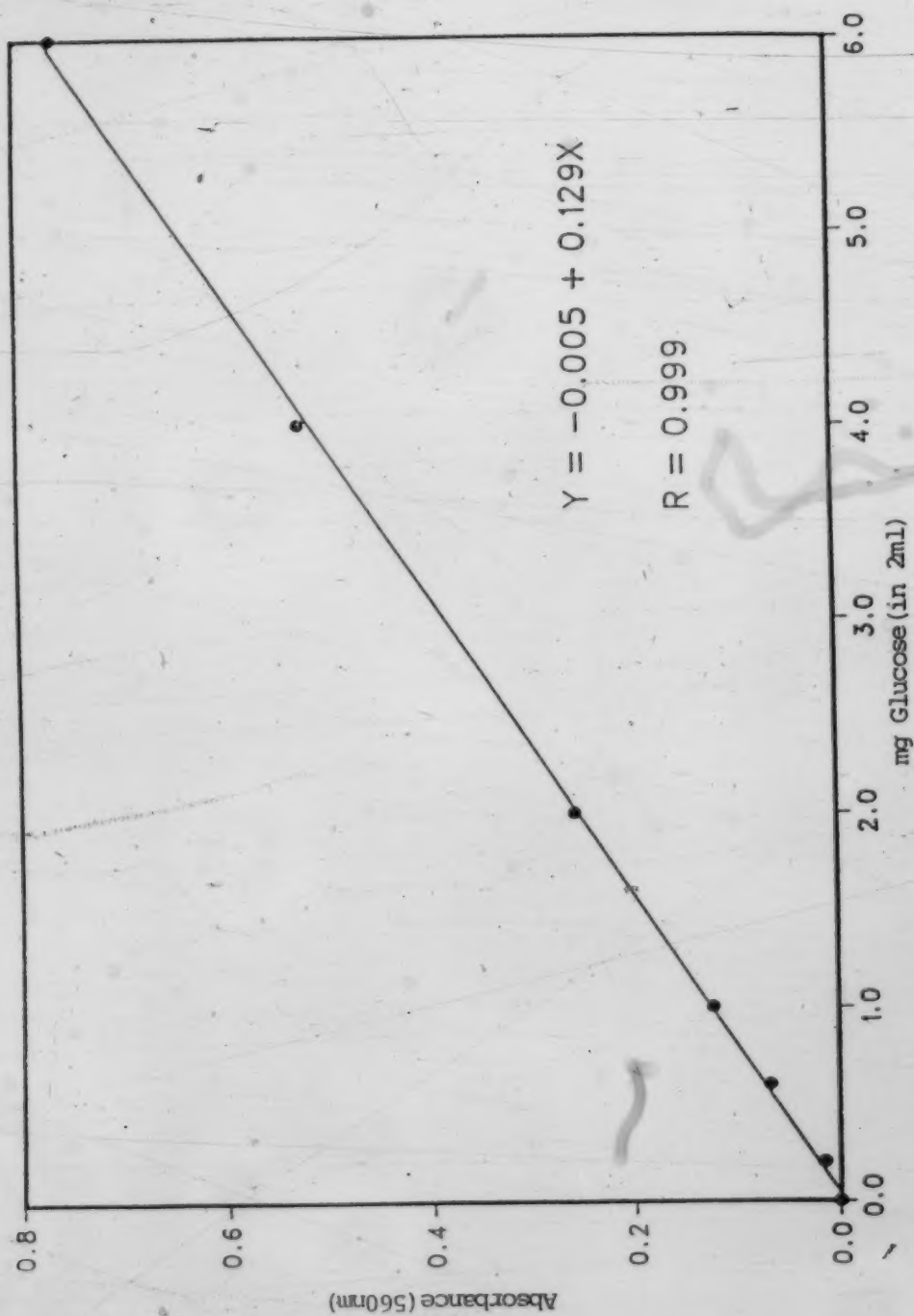


Figure 1. Calibration curve for the reducing sugar (Glucose)

made up to volume by adding distilled water. Two millilitres of the contents of each volumetric flask were pipetted into a series of dry, clean, chilled test tubes, and a 2 ml of distilled water was pipetted into two other test tubes, and the latter served as blanks. Samples were triplicated. Each tube thus contained 0.2, 0.6, 1.0, 2.0, 4.0 and 6.0 mg of glucose. Two millilitres of the 3,5-dinitrosalicylate reagent were added to each test tube, mixed well on a vortex mixer, covered with a marble and placed in a boiling water bath for five minutes. The test tubes were then cooled immediately in ice bath. The contents of each test tube was then diluted with 21 ml of distilled water, and then mixed well on a vortex mixer. The absorbance was read at 560 nm using the blank to standardize the spectrophotometer (Spectronic 21). A standard curve was then prepared by plotting mg glucose vs. absorbance.

- c. Sample preparation - Two to three potatoes (depending on size) were weighed, peeled and diced into small cubes by chopping with a sharp kitchen knife. The chopped potatoes were mixed well and a 25 g sample was weighed and placed in a waring blender with 100 ml of chilled distilled water. The sample was blended for exactly one minute at low speed. The homogenate was filtered through Whatman #4 filter paper into a 50 ml dry, clean, chilled erlenmyer flask. The contents of the flask was mixed thoroughly, the flask was wrapped and placed in ice immediately. Two millilitre of the extract was pipetted into three dry, clean, chilled test tubes (triplicate sample) and a 2 ml of distilled water into two other test tubes to be used later as blanks. Two millilitres of 3,5-dinitrosalicylate reagent were added to each test tube, mixed well and the procedure continued as in the preparation of the standard curve (Ross, 1975).
- d. Calculation of % reducing sugars - The % reducing sugars was calculated as follows:

25 g of raw potatoes in 100 ml of distilled water provides 125 ml extract, therefore a 2 ml extract was equivalent to 400 mg of raw potatoes.

$$\% \text{ reducing sugars} = \frac{\text{Absorbance of sample}}{\text{slope of the standard curve} \times 400 \text{ mg}} \times 100\%$$

$$\% \text{ reducing sugars} = \frac{\text{Absorbance of sample}}{\text{slope of the standard curve} \times 4}$$

3.2.6.2 Sucrose content analysis

The sucrose content was determined by the anthrone colorimetric method developed by Van Handel (1968) and adopted for potatoes by Sowokinos (1978).

The reagents used in sucrose determination were prepared as follows:

- a. Anthrone reagent - A diluted sulphuric acid solution was prepared by adding 76 ml of concentrated sulphuric acid (analytical grade) to 30 ml distilled water slowly while stirring. When the sulphuric acid solution was cooled to touch, it was added to 0.15 g of anthrone and stirred for two hours until all the anthrone was dissolved. The anthrone reagent was kept in a dark bottle and stored in a refrigerator at 4°C when not in use.
- b. 30% potassium hydroxide - This reagent was prepared by mixing 35.29 g of solid 85% potassium hydroxide (mw=56.11) in a 100 ml of distilled water. The mixture was stirred with a glass rod until all the pellets were dissolved. The reagent was kept in a dark bottle and stored in a refrigerator.
- c. Sucrose standard - Twenty-five millilitres of distilled water were added to 25 mg of dried sucrose (mw=342.2). The solution was mixed well and kept in a refrigerator (4°C). Fresh sucrose solution was prepared each day. One millilitre of this solution was equivalent to 1 mg sucrose.
- d. Sample preparation - Two to four potato tubers (depending on size) were weighed, peeled manually with a potato peeler and cut lengthwise into slices. Random pieces were selected and a 200 g sample was weighed.

The juice from the 200 g sample was extracted using an electric Braun juicerator, and the juice was collected in a 600 ml chilled beaker, previously marked to 430 ml. The juicerator was washed three times with 100 ml chilled distilled water, while it was running, with two to three minutes between washings using a 100 ml chilled graduated cylinder. The extract volume was made up to 430 ml with cold distilled water, mixed well with a clean chilled glass rod. The beaker was then covered with stretch and seal film, wrapped in aluminum foil and placed in a refrigerator at 4°C for one hour to settle. The extract was then ready for sucrose analysis.

During the one hour holding period, the analysis for reducing sugars was run.

The juice extract was removed after one hour from the refrigerator cautiously to avoid mixing the contents, and placed in ice immediately.

A series of dry, clean, chilled test tubes were prepared. To each of three test tubes was added 1 ml of the juice extract using an automatic epindorf repipetter. Ten millilitres of cold distilled water was added to each of the three test tubes, and this made a dilution of 1:11.

From the 1:11 dilution made, 0.1 ml of the contents of each test tube transferred into three other dry, clean, chilled test tubes with screw caps. To two other chilled test tubes, 0.1 ml of sucrose standard was added, and 0.1 ml of cold distilled water was added to two other chilled test tubes to serve as blanks later. To each test tube, 0.1 ml of 30% KOH was added. The caps were closed and the contents were mixed by shaking (vortexing). The tubes were then heated in a dry bath at 100°C for five minutes to destroy the reducing sugars. The samples were then allowed to cool at room temperature, and 3 ml of Anthrone reagent were added to each of the tubes. The caps were closed, the contents were mixed well again on a vortex mixer, and the tubes were incubated in a water bath

at 40°C for 40 minutes, during which time the tubes were shaken at intervals of 10 minutes to assure homogeneity. Subsequent to cooling at room temperature, the absorbance of the samples were taken at 620 nm using the blank to standardize the spectrophotometer (Spectronic 21).

During the 40 minute incubation period, the chipping process was performed.

- e. The sucrose content was calculated as follows: The sample extract was made up to 430 ml originally. Ten millilitres of distilled water was used for diluting 1 ml of the juice extract. The dilution extract was 1:11.

D.F. = Dilution Factor

O.D. = Optical Density

S.R. = (sucrose content of sample or sucrose rating)

$$\text{Dilution Factor} = \frac{430 \text{ ml}}{0.1 \text{ ml (assay volume)}} \times \frac{11 \text{ (dilution factor)}}{200 \text{ g tuber}}$$

$$\text{D.F.} = 236.5/\text{g}$$

$$\text{S (mg sucrose in 0.1 ml extract)} = \frac{\text{O.D.}}{\text{O.D.}} \times 0.1 \text{ mg (sucrose standard)}$$

$$\text{S.R.} = \frac{\text{O.D. of extract} \times 0.1 \text{ mg}}{\text{O.D. of standard}} \times \text{D.F.}$$

$$\text{S.R.} = \text{mg sucrose/g tuber}$$

3.2.6.3 Chip making and chip color scoring

Two to three potatoes were shaped and sliced using the electric potato slicer (Braun), thickness of 1 mm.

The slices were rinsed under tap water few times to remove the starch. The slices were then placed between two layers of paper towel to remove excess moisture. The dried slices were fried in vegetable oil, boiling at 180-185°C. Chips were fried until sizzling stopped which took from two to three minutes. The fried chips were then drained on paper towels, cooled at room temperature, and the chip color was measured subjectively using U.S.D.A. Standard Chip Color Charts for measuring chip color. The colored chart rates range from 10 to 100, 10 being the darkest color and 100 the lightest.

4. RESULTS

The specific gravity of Norchip potatoes was 1.080, and the percent dry matter was 20.22.

4.1 Storage duration

Analysis of variance of chip color, % reducing sugars and sucrose content (Appendix 1, 2 and 3) showed that the effect of storage duration is significant ($P < 0.001$) on the three variables.

Data listed in Table 1, shows that the treatment means for the chip color values for the entire storage duration, from week 1 to week 10, the chip color measurements increased from 22 to 51. At week 7, the chip color mean value was decreased to 41, and at week 8 the number started to increase again.

As shown in Table 1, the treatment means for the % reducing sugars, is with 0.784 at week 1, increased to 1.000 at week 2 then it declined until the end of the storage period. At week 7 the number increased again. The treatment means for the sucrose content, is 7.656 and decline until the end of the storage period except a slight increase occurred at week 7 as was the case with % reducing sugars.

4.2 Sprout inhibitor (C.I.P.C.)

Analysis of variance of chip color, % reducing sugars and sucrose content (Appendix 1, 2 and 3) showed that the effect of the sprout inhibitor (C.I.P.C.) on chip color is significant ($P = 0.014$). The effect of the sprout inhibitor (C.I.P.C.) is not significant on % reducing sugars and sucrose content.

In Table 2, it is shown that the treatment mean for chip color, for tubers treated with the sprout inhibitor (C.I.P.C.) is 37, while the treatment means for untreated tubers is 38, and the difference is significant ($P = 0.014$). The treatment means for % reducing sugars for treated tubers is 0.564 and for untreated tubers is 0.542. The difference is not significant. The treatment means for sucrose content for treated tubers is 3.597 and for untreated tubers is

3.554. Again, the difference is not significant.

4.3 The Storage Temperature

Analysis of variance of chip color, % reducing sugars and sucrose content (Appendix 1, 2 and 3) showed that the effect of temperature on the three variables is significant ($P < 0.001$).

Inspection of Table 3, shows the treatment means for chip color is 29 at 6°C, increased to 39 at 9°C and 46 for 12°C. The difference between all the treatment means is significant ($P < 0.001$). The % reducing sugars, is 0.737 at 6°C decreased to 0.521 at 9°C, and 0.400 at 12°C. The difference between all the treatment means is significant ($P < 0.001$). The sucrose content is 5.327 at 6°C, decreased to 3.088 at 9°C and 2.311 at 12°C. The difference between the treatment means at the three storage temperatures is significant ($P < 0.001$).

4.4 The sprout inhibitor (C.I.P.C.) and temperature interaction

Results listed in Appendix 4 shows that treatment means of chip color, % reducing sugars and sucrose content for C.I.P.C. and temperature interactions are not significant. For example, the chip color score for No C.I.P.C., 6°C and C.I.P.C., 6°C is 29; for No C.I.P.C., 9°C is 40 and 39 for C.I.P.C., 9°C; and 46 for both No C.I.P.C., 12°C and C.I.P.C., 12°C.

4.5 Regression analysis of the three variables on storage duration

All the three regression equations and R^2 (coefficient of determination) values of chip color, % reducing sugars and sucrose content for the three storage temperatures (6, 9 and 12°C), are significant ($P < 0.001$), Tables (4, 5 and 6).

Data listed in Table 4 shows that at 6°C, 81.7% of the variations in chip color is due to storage durations, at 9°C, 81.5% and 89.5% at 12°C. At 6°C, the b_0 (intercept) and b_1 (slope) values are significant ($P < 0.001$) and ($P = 0.002$) respectively. The b_2 (slope) value is not significant. The nonsignificance of b_2 value is observed, as the regression line at 6°C is not

significantly curved and the line resembles a straight line. At 9°C, the b_0 and b_1 values are significant ($P < 0.001$) and b_2 ($P = 0.002$). The regression line is significantly curved. At 12°C, all the b values, b_0 , b_1 and b_2 are significant ($P < 0.001$) and the regression line is significantly curved, (Figure 2).

Results of Table 5 shows that at 6°C, 61.0% of the variations in % reducing sugars is due to storage duration, 69.1% at 9°C and 81.0% at 12°C. At 6°C, the b_0 value is significant ($P < 0.001$), while b_1 and b_2 are not significant. The nonsignificance of b_1 and b_2 is observed, as the regression line is not significantly curved, and the line resembles a straight line. At 9°C, the b_0 and b_1 values are significant ($P < 0.001$), and b_2 value is significant ($P = 0.010$). The regression line is significantly curved. At 12°C, all the b values are significant ($P < 0.001$), and the regression line is significantly curved, (Figure 3).

Data listed in Table 6 shows that at 6°C, 46.7% of the variations in sucrose content is due to storage duration, 78.5% at 9°C and 52.4% at 12°C. At 6°C the b_0 and b_1 values are significant ($P < 0.001$) and the b_2 value is significant ($P = 0.009$). This significance is observed on the regression line as it is significantly curved. At 9°C and 12°C, the b_0 , b_1 and b_2 values are significant ($P < 0.001$). This significance is observed on the regression lines, as the two regression lines are significantly curved, (Figure 4).

All the regression equations and R^2 values of chip color, % reducing sugars and sucrose content on storage duration for C.I.P.C. and temperature combinations are significant ($P < 0.001$), Tables (7, 8 and 9).

Results of Table 7 shows that at No C.I.P.C., 6°C, 82.6% of the variations in chip color is due to storage duration, and 81.4% is due to storage duration at C.I.P.C., 6°C. The b_0 values are significant ($P < 0.001$) for both interactions. The b_1 value is significant ($P = 0.021$) and the b_2 value is not significant for No C.I.P.C., 6°C. The b_1 and b_2 values are not significant for C.I.P.C., 6°C. Both regression lines are not significantly curved, (Figure 5). At No C.I.P.C., 9°C, 82.9% of the variations in chip color is due to storage duration and 91.2% at C.I.P.C., 9°C. The b_0 and b_1 values are significant ($P < 0.001$), and the b_2 value is

significant ($P < 0.003$) for No C.I.P.C., 9°C. The b_0 and b_1 values are significant for C.I.P.C., 9°C ($P < 0.001$) and the b_2 value is not significant. The regression line for No C.I.P.C., 9°C is significantly curved, while the regression line for C.I.P.C., 9°C is not significantly curved, (Figure 5).

At No C.I.P.C., 12°C, 90.5% of the variations in chip color is due to storage duration, and 88.8% at C.I.P.C., 12°C. The b_0 and b_1 values are significant ($P < 0.001$), and the b_2 value is significant ($P = 0.004$) for both interactions. The significance of both regression lines is observed and both the lines are significantly curved, (Figure 5).

Data listed in Table 8 shows that 61.8% of the variations in % reducing sugars is due to storage duration at No C.I.P.C., 6°C and 65.9% at C.I.P.C., 6°C. The b_0 value is significant for both interactions, while b_1 and b_2 values are not significant. The two regression lines for both interactions are not significantly curved, (Figure 6).

At No C.I.P.C., 9°C, 61.9% of the variations in % reducing sugars is due to storage duration and 78.4% at C.I.P.C., 9°C. The b_0 value is significant ($P < 0.001$), the b_1 value is significant ($P = 0.005$) and the b_2 is not significant for No C.I.P.C., 9°C. The regression line is not significantly curved. The b_0 and b_1 values are significant ($P < 0.001$) and the b_2 value is significant ($P = 0.037$) for C.I.P.C., 9°C interaction. The regression line is significantly curved, (Figure 6).

At No C.I.P.C., 12°C, 86.2% of the variations in % reducing sugars is due to storage duration and 76.5% at C.I.P.C., 12°C. The b_0 , b_1 and b_2 values are significant ($P < 0.001$) for No C.I.P.C., 12°C. The b_0 and b_1 values are significant ($P < 0.001$), while the b_2 value is significant ($P = 0.007$) for C.I.P.C., 12°C. The two regression lines are significantly curved, (Figure 6).

Results of Table 9 shows that 41.6% of the variations in sucrose content is due to storage duration at No C.I.P.C., 6°C and 54.6% at C.I.P.C., 6°C. The b_0 values for both interactions are significant ($P < 0.001$). The b_1 value is significant ($P = 0.046$) for No C.I.P.C., 6°C, while the b_2 value is not significant. The regression line is not significantly

curved. The b_1 value is significant ($P < 0.001$) and the b_2 value is significant ($P = 0.017$) for C.I.P.C., 6°C. The regression line is significantly curved.

At No C.I.P.C., 9°C, 80.4% of the variations in sucrose content is due to storage duration and 77.0% at C.I.P.C., 9°C. The b_0 , b_1 and b_2 values are significant ($P < 0.001$) for both interactions. Both regression lines are significantly curved, (Figure 7).

At No C.I.P.C., 12°C, 69.1% of the variations in sucrose content is due to storage duration and 51.1% at C.I.P.C., 12°C. The b_0 , b_1 and b_2 values are significant ($P < 0.001$) for both interactions and the two regression lines are significantly curved, (Figure 7).

4.6 Correlation of chip color to other quality parameters and storage duration

Data listed in Table 10 shows that all the correlations are significant ($P \leq 0.01$). The correlation between chip color and % reducing sugars, chip color and sucrose content as well as chip color and storage duration. All the correlation values are significant ($P \leq 0.01$) at 28 d.f.

There is a strong significant negative correlation between chip color and % reducing sugars. The highest value (-0.961) is at No C.I.P.C. and 12°C, while the lowest value (-0.865) is at No C.I.P.C., 6°C).

The correlation of chip color to sucrose content is significant, but less strong and negative. The highest correlation value (-0.843) is at No C.I.P.C., 9°C, and the lowest correlation value (-0.667) is at C.I.P.C., 12°C.

The correlation between chip color and storage duration is significant, strong and positive. The highest correlation (0.951) is at C.I.P.C., 9°C, and the lowest correlation value (0.874) is at No C.I.P.C., 9°C.

Table 1. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for each storage duration.

Storage duration (week)	Chip color (U.S.D.A.) (Standard)	Reducing sugars (%)	Sucrose content (mg/g fw)
1	22	0.784	7.656
2	24	1.000	6.441
3	31	0.715	4.756
4	36	0.562	2.948
5	38	0.516	2.342
6	43	0.439	2.286
7	41	0.462	2.721
8	45	0.387	2.435
9	48	0.356	2.311
10	51	0.306	1.858
SEM	0.946	0.025	0.267
Probability	0.001	0.001	0.001

Table 2. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for the two levels of C.I.P.C.

Sprout inhibitor (C.I.P.C.)	Chip Color (U.S.D.A.) (Standard)	Reducing sugars (%)	Sucrose content (mg/g fw)
No C.I.P.C.	38	0.542	3.554
C.I.P.C.	37	0.564	3.597
SEM	0.297	0.010	0.174
Probability	0.014	0.130	0.861

Table 3. Treatment means for the three variables, chip color, % reducing sugars and sucrose content for the three storage temperatures (6, 9 and 12°C).

Temperature (°C)	Chip Color (U.S.D.A.) (Standard)	Reducing sugars (%)	Sucrose content (mg/g fw)
6	29	0.737	5.327
9	39	0.521	3.088
12	46	0.400	2.311
SEM	0.364	0.012	0.213
Probability	0.001	0.001	0.001

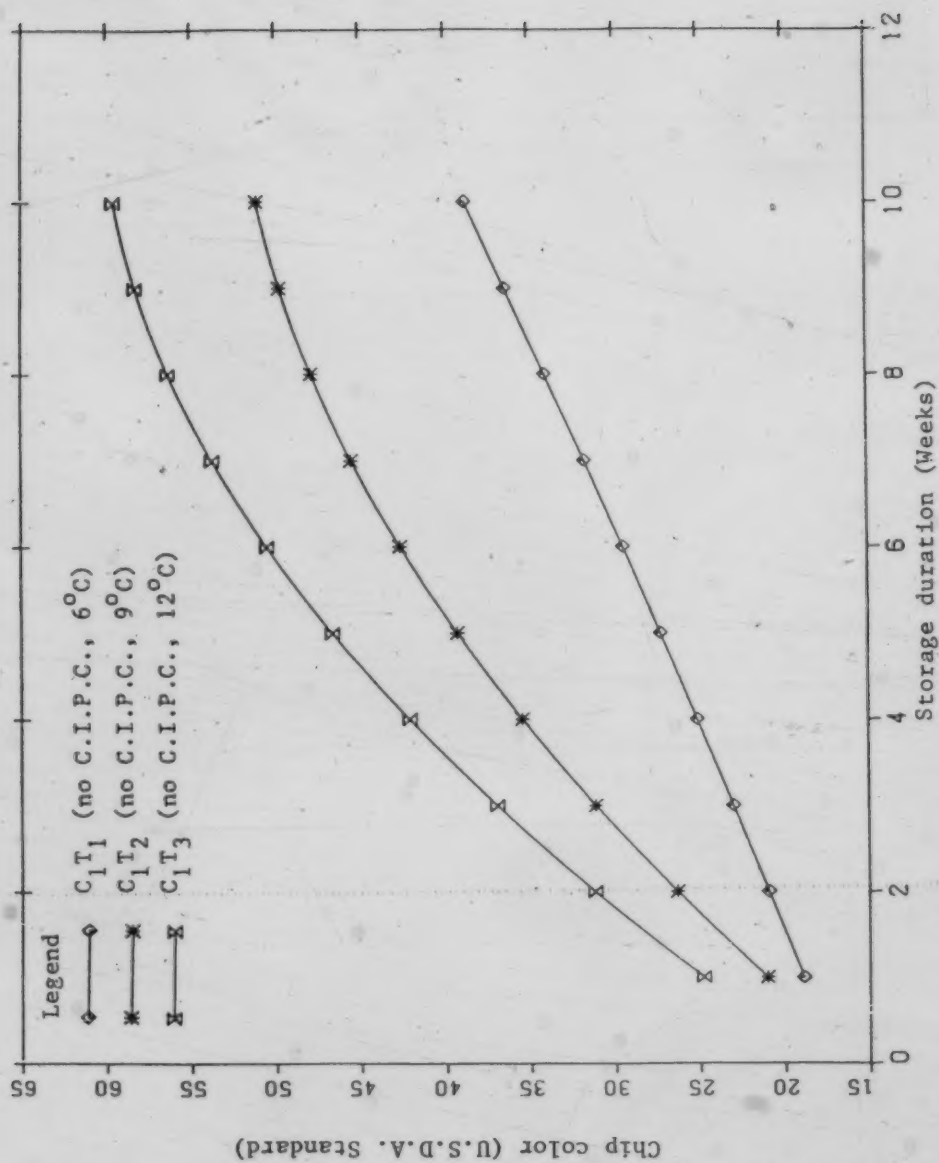


Figure 2. Regression of chip color on storage duration for each of the three storage temperatures.

Table 4. Regression of chip color on storage duration for the three storage temperatures (6, 9 and 12°C) without C.I.P.C. application.

Temperature	t-test for individual coefficients	b_0	b_1	b_2	$F(2,11)$	Probability	R^2
6°C		16.931	1.964	0.022	126.915	0.001	0.817
	$t(17)$	11.437	3.177	0.403			
	probability	0.001	0.002	0.688			
9°C		15.250	6.042	-0.246	162.556	0.001	0.851
	$t(17)$	7.590	7.200	-3.312			
	probability	0.001	0.001	0.002			
12°C		17.764	7.366	-0.319	244.092	0.001	0.895
	$t(17)$	9.320	9.253	-4.521			
	probability	0.001	0.001	0.001			

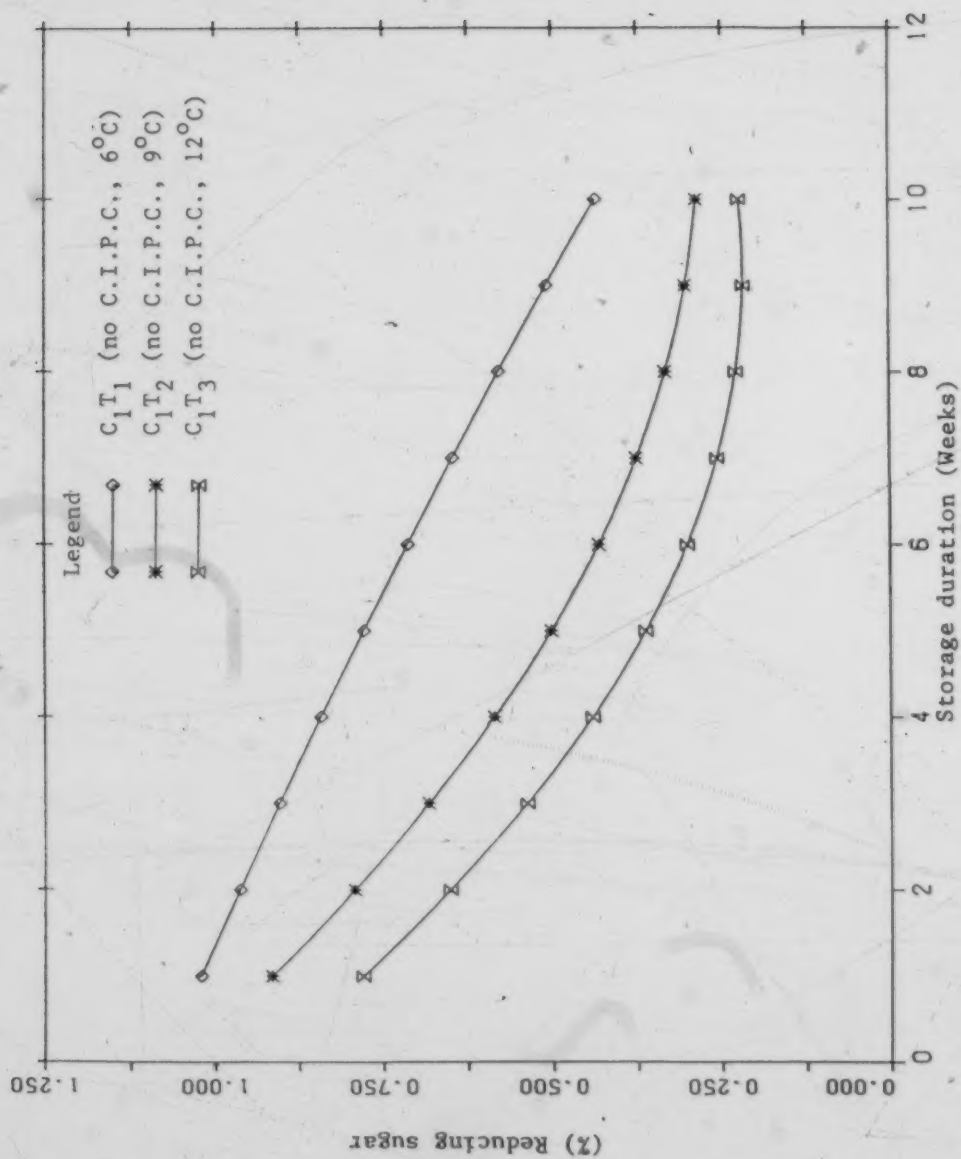


Figure 3. Regression of % reducing sugars on storage duration for each of the three storage temperatures.

Table 5. Regression of % reducing sugars on storage duration for the three storage temperatures (6, 9 and 12°C) without C.I.P.C. application.

Temperature	t-test for individual coefficients	b ₀	b ₁	b ₂	F(2,37)	probability	R ²
6°C		1.078	-0.559	-0.001	44.596	0.001	0.610
	t(37) probability	14.541 0.001	-1.801 0.077	-0.322 0.748			
9°C		1.052	-0.144	0.007	63.486	0.001	0.691
	t(37) probability	15.453 0.001	-5.049 0.001	2.663 0.010			
12°C		0.927	-0.155	0.009	121.178	0.001	0.810
	t(37) probability	20.663 0.001	-8.296 0.001	5.132 0.001			

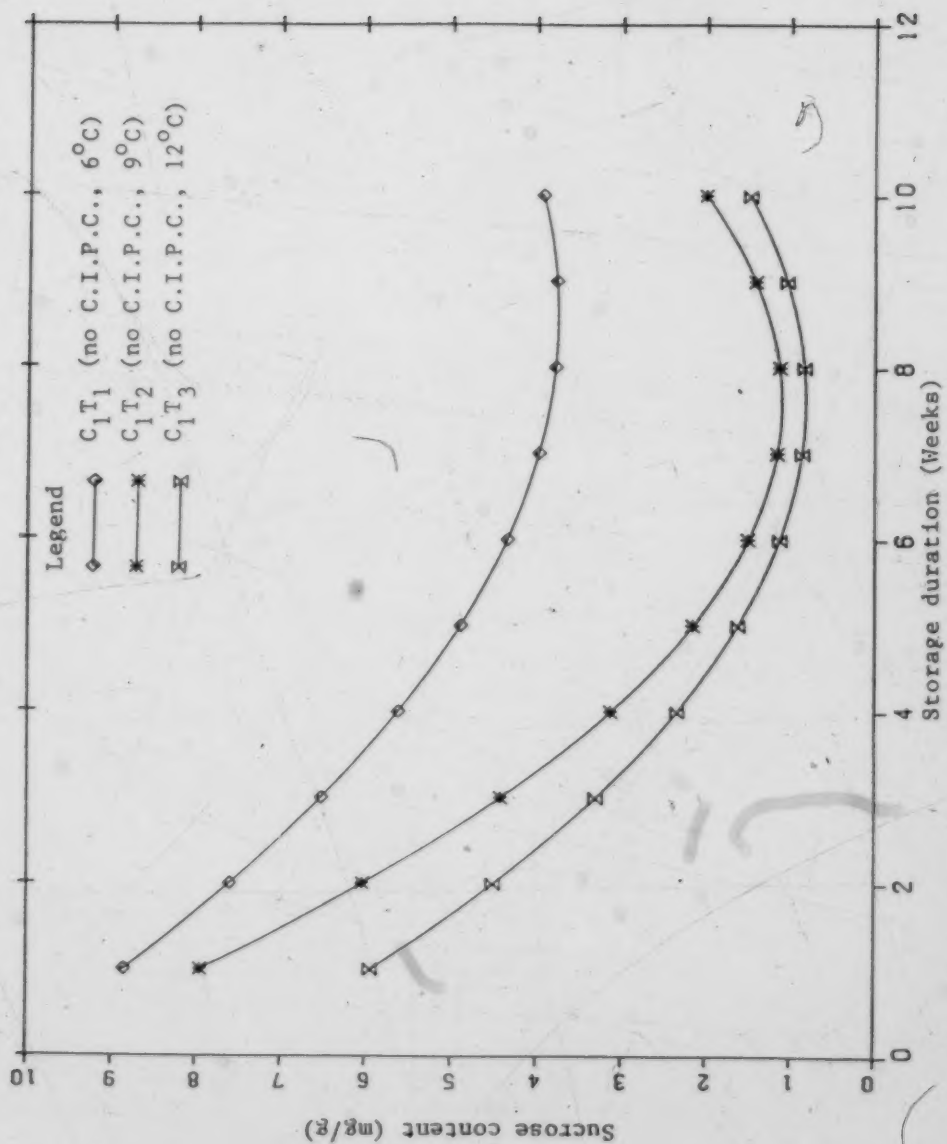


Figure 4. Regression of sucrose content on storage duration for each of the three storage temperatures.

Table 6. Regression of sucrose content on storage duration for each of the three temperatures (6, 9 and 12°C) without C.I.P.C. application.

Temperature	t-test for individual coefficients	b ₀	b ₁	b ₂	F(1, 57)	probability	R ²
6°C	t(57) probability	10.282 11.516 0.001	-1.522 -4.081 0.001	0.089 2.684 0.009	24.261	0.001	0.467
9°C	t(57) probability	10.165 17.854 0.001	-2.386 -10.033 0.001	0.157 7.453 0.001	104.147	0.001	0.785
12°C	t(57) probability	7.593 9.789 0.001	-1.777 -5.485 0.001	0.117 4.063 0.001	31.399	0.001	0.524

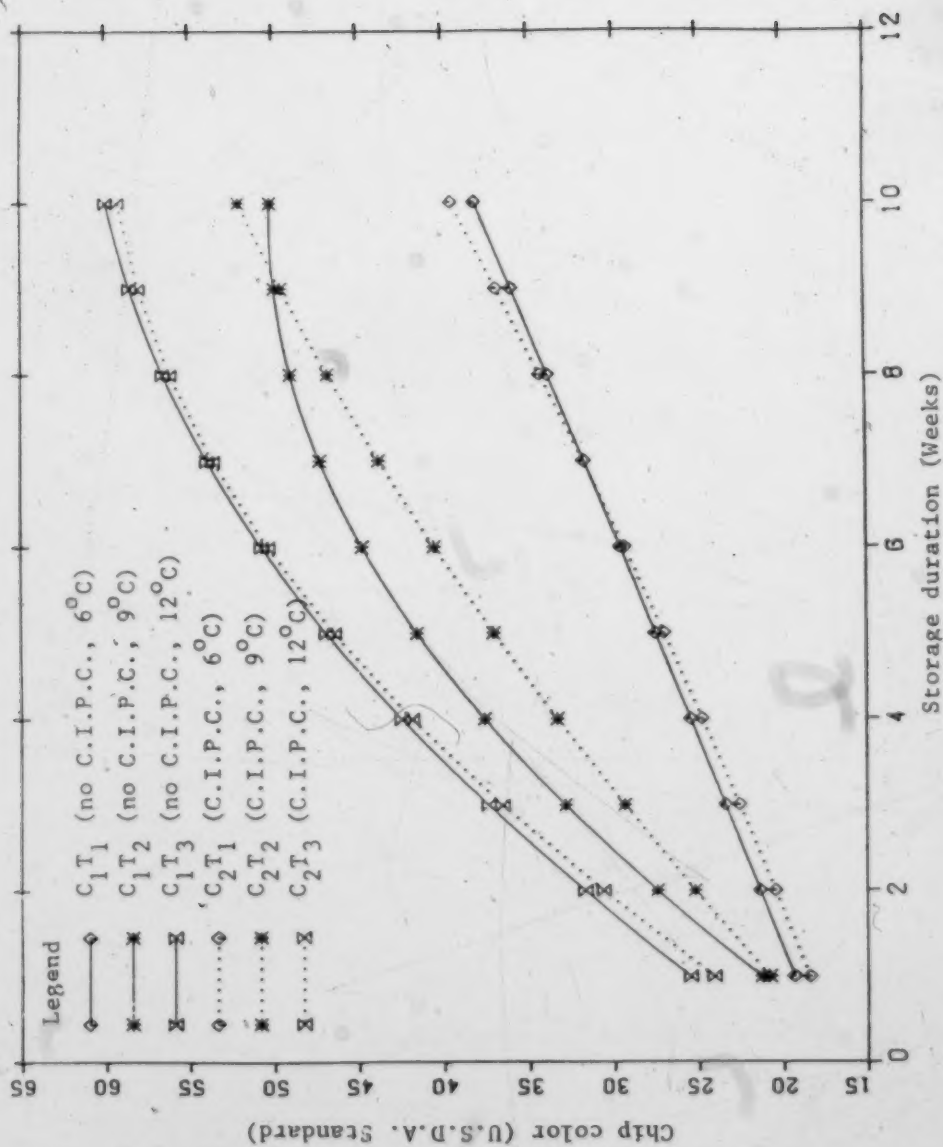


Figure 5. Regression of chip color on storage duration for C.I.P.C. and temperature combinations.

Table 7. Regression of chip color on storage duration for C.I.P.C. and temperature combinations.

Treatments	t-test for individual coefficients	b_0	b_1	b_2	$F(1,17)$	probability	R^2
No C.I.P.C., 6°C		17.361	2.011	0.006	64.304	0.001	0.826
	$t(17)$	8.857	2.457	0.087			
	probability	0.001	0.021	0.931			
No C.I.P.C., 9°C		14.361	7.299	-0.372	65.674	0.001	0.829
	$t(17)$	4.616	5.617	-3.235			
	Probability	0.001	0.001	0.003			
No C.I.P.C., 12°C		18.667	7.152	-0.303	128.932	0.001	0.905
	$t(17)$	7.205	6.609	-3.161			
	probability	0.001	0.001	0.004			
C.I.P.C., 6°C		16.500	1.917	0.038	59.215	0.001	0.814
	$t(17)$	7.197	2.002	0.447			
	probability	0.001	0.055	0.659			
C.I.P.C., 9°C		16.139	4.784	-0.120	139.151	0.001	0.912
	$t(17)$	7.246	5.143	-1.457			
	probability	0.001	0.001	0.157			
C.I.P.C., 12°C		16.861	7.580	-0.335	107.060	0.001	0.888
	$t(17)$	5.789	6.231	-3.104			
	probability	0.001	0.001	0.004			

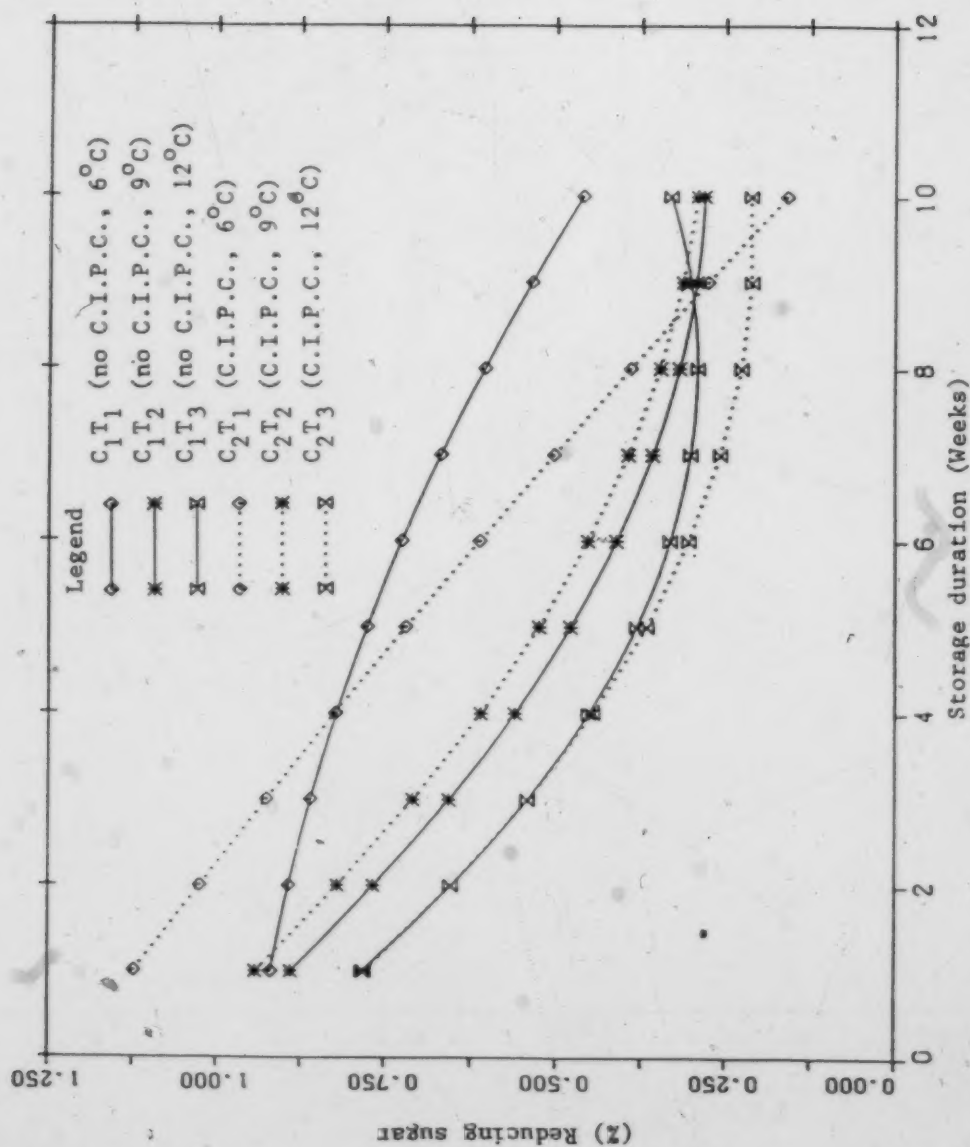


Figure 6. Regression of % reducing sugars on storage duration for C.I.P.C. and temperature combinations.

Table 8. Regression of % reducing sugars on storage duration for the C.I.P.C. and temperature combinations.

Treatments	t-test for individual coefficients	b ₀	b ₁	b ₂	F(1,17)	probability	R ²
No C.I.P.C., 6°C		0.940	-0.018	-0.003	21.861	0.001	0.618
	t(17)	11.341	-0.516	-0.974			
	probability	0.001	0.610	0.339			
No C.I.P.C., 9°C		1.026	-0.144	0.007	21.904	0.001	0.619
	t(17)	9.078	-3.060	1.667			
	probability	0.001	0.005	0.107			
No C.I.P.C., 12°C		0.932	-0.160	0.009	84.349	0.001	0.862
	t(17)	17.417	-7.155	4.544			
	probability	0.001	0.001	0.001			
C.I.P.C., 6°C		1.217	-0.094	0.001	26.068	0.001	0.659
	t(17)	10.234	-1.887	0.277			
	probability	0.001	0.070	0.784			
C.I.P.C., 9°C		1.078	-0.143	0.006	48.961	0.001	0.784
	t(17)	13.567	-4.299	2.192			
	probability	0.001	0.001	0.037			
C.I.P.C., 12°C		0.921	-0.151	0.008	43.858	0.001	0.765
	t(17)	12.299	-4.821	2.899			
	probability	0.001	0.001	0.007			

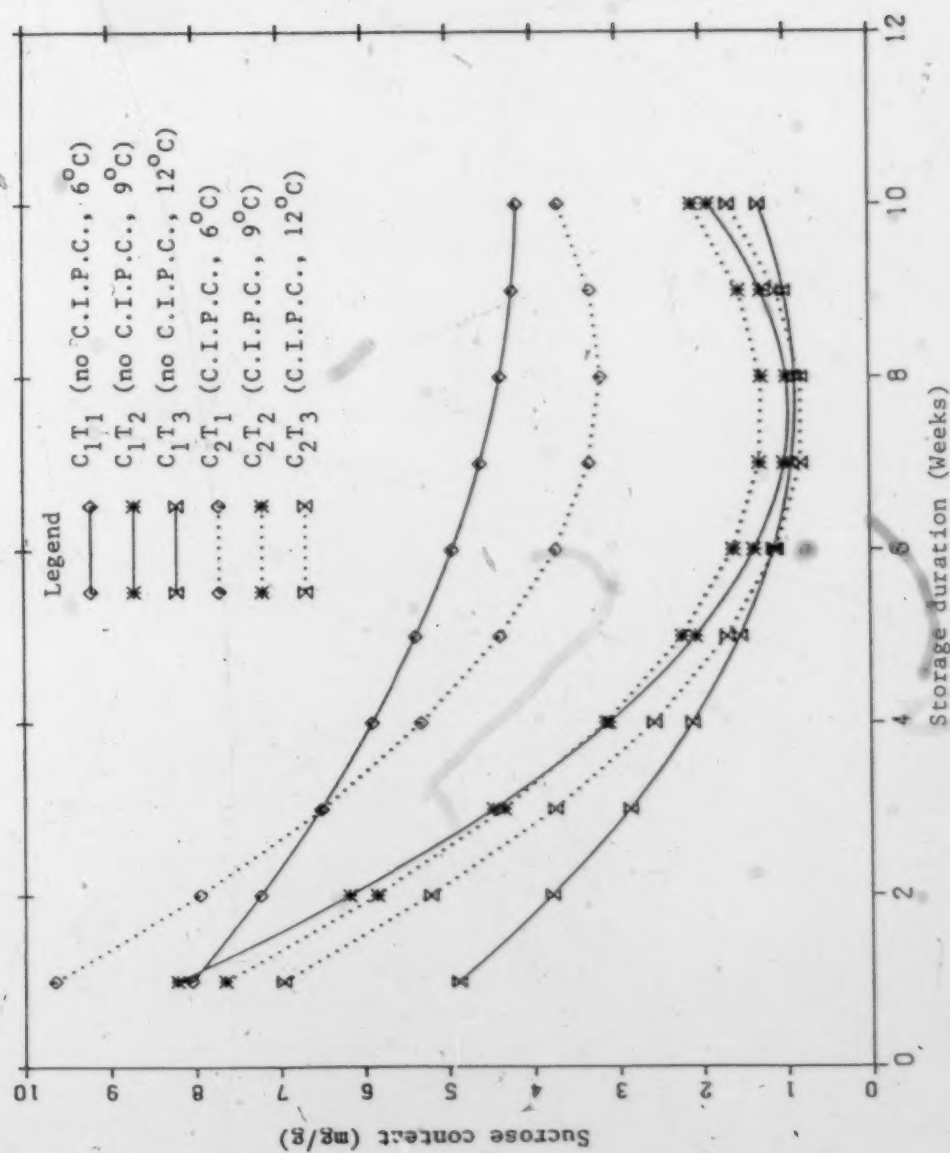


Figure 7. Regression of sucrose content on storage duration for C.I.P.C. and temperature combinations.

Table 9. Regression of sucrose content on storage duration for the C.I.P.C. and temperature combinations.

Treatments	t-test for individual coefficients	b_0	b_1	b_2	$F(1,17)$	probability	R^2
No C.I.P.C., 6°C	$t(17)$ probability	8.948 8.245 0.001	-0.948 -2.092 0.046	-0.047 1.174 0.251	9.625	0.001	0.416
No C.I.P.C., 9°C	$t(17)$ probability	10.585 12.733 0.001	-2.535 -7.301 0.001	0.167 5.421 0.001	55.234	0.001	0.804
No C.I.P.C., 12°C	$t(17)$ probability	6.168 9.842 0.001	-1.362 -5.205 0.001	0.088 3.779 0.001	30.185	0.001	0.691
C.I.P.C., 6°C	$t(17)$ probability	11.615 8.364 0.001	-2.095 -3.612 0.001	0.130 2.533 0.017	16.214	0.001	0.546
C.I.P.C., 9°C	$t(17)$ probability	9.746 12.023 0.001	-2.237 -6.607 0.001	0.147 4.910 0.001	45.088	0.001	0.770
C.I.P.C., 12°C	$t(17)$ probability	9.018 5.450 0.001	-2.191 -3.752 0.001	0.146 2.814 0.009	14.112	0.001	0.511

Table 10. Correlation of chip color to % reducing sugars, sucrose content and storage duration for the C.I.P.C. and temperature combinations.

Treatments	Reducing sugars	Sucrose content	Storage duration
No C.I.P.C., 6°C	-0.865	-0.671	0.909
No C.I.P.C., 9°C	-0.896	-0.843	0.874
No C.I.P.C., 12°C	-0.961	-0.793	0.933
C.I.P.C., 6°C	0.868	-0.723	0.902
C.I.P.C., 9°C	-0.920	-0.776	0.951
C.I.P.C., 12°C	-0.937	-0.667	0.921

Correlation coefficient ≥ 0.463 are significant ($P \leq 0.01$). (Steele and Torrie, 1980).

Number of observations(N) = 30.

BLANK PAGE

5. DISCUSSION

The discussion is divided in the same manner as the result section.

5.1 The Storage duration

Chip color improved and increased in value at the end of the storage period for all the three storage temperatures, whether tubers were treated with C.I.P.C. or not. These results are similar to those of Mazza, *et al.* (1983) and Schippers, (1975). The levels of % reducing sugars and sucrose content declined and continued to decline until the end of the storage duration for all the three temperatures, whether tubers were treated or not. These results are in agreement with those of Mazza, (1983); Burton and Wilson, (1978); Cunningham, *et al.* (1971) and Stevenson and Cunningham (1961).

At the two higher temperatures (9 and 12°C), the rate of improving the chip color (higher values) slowed down after storing the tubers for eight weeks, (Figure 2). The rate of decline in the level of % reducing sugars started to slow down after storing the tubers for eight weeks at the 9 and 12°C, (Figure 3). While the rate of decline in the levels of sucrose content started to slow down after six weeks of storage period. At 9° and 12°C. The sucrose content levelled off for one week, then started to increase again after eight weeks of storage until the end of the storage period. At 6°C, the rate of decline in the level of sucrose slowed down after seven weeks of storage period, then it levelled off for one week, and started to rise again after nine weeks of storage period, (Figure 4). At the highest temperature (12°C) more of the variations in chip color and % and reducing sugars are explained by storage duration. (Tables 4, 5 and 6). More of the variations in sucrose content is explained by the storage duration at 9°C, while the remaining are due to other sources of variability in the experiment.

The changes in chip color values correspond to the changes in % reducing sugars, while the changes in % reducing sugars occurred one week after the changes in sucrose content, i.e., there is a lag period of one week between changes in sucrose content level and changes in % reducing sugars level, particularly at 12°C. Mazza (1983) stated that the actual chip color is

a result of the synergistic action of both reducing sugars, sucrose content and tuber temperature. It is common knowledge that the reducing sugar content is crucial in the development of the dark, sweet-tasting potato chip color, (Agle and Woodbury, 1968; Habib and Brown, 1957). In this study, the results indicate that the chip color first corresponds to changes in the % reducing sugars, since the reducing sugars participate directly in the browning reactions during chip frying, (Miller, 1975, Shellenberger, 1959). The potato tubers used in this study were mature, and mature tubers contain less reducing sugars. Mature tubers contain less amounts of sucrose than immature tubers, (Clegg and Chapman, 1962), and produce lighter chips, (Clegg and Chapman, 1962). The 'Norchip' potato cultivar is known to be an excellent potato chipper, it has an inherent ability of low reducing sugar accumulation, (Dowelle and Stalknecht, 1978). The poor potato chippers has inherently higher levels of reducing sugars (Samotus and Schwimmer, 1962). Norchip potato cultivar has an inherent ability to reach a sucrose content of less than 2.8 mg / g tuber prior to obtaining physical maturity, (Nelson and Sowokinos, 1983; Sowokinos, 1978).

5.2 The Sprout inhibitor (C.I.P.C.)

The chip color was darker (lower in value) when tubers were treated with C.I.P.C., (Table 2). This contradicts the results of the experiments of Khurana and Randhawa (1985); Schippers (1975) and Zaehring (1966). The concentration of C.I.P.C. applied in this study was double that recommended for spraying and four fold of that used by Khurana and Randhawa (1985). The high concentration of C.I.P.C., and the dipping method may affect other chemical constituents of the tuber other than the sugars which led to this result. In spite of the high concentration of C.I.P.C. applied in this study, the % reducing sugars and sucrose content did not change significantly when tubers were treated with C.I.P.C.. These results are similar to those of Khurana, *et al.* (1985) and Zaehring (1966).

5.3 The Storage temperature

The highest storage temperature in this study produced the lightest chip color, the lowest % reducing sugars and sucrose content, (Table 3). But at the highest storage temperature (12°C), the chip color started to get lighter (highest values) at a slower rate after nine weeks of storage, (Figure 2). At 9 and 12°C, the rate of decline in % reducing sugars started to slow down after storing tubers for eight weeks, (Figure 3), while the rate of decrease in the sucrose content level started to slow down after six weeks of storage, (Figure 4). The sucrose level remained unchanged for one week, then it started to increase after eight weeks of storage. The levelling off and rise in sucrose content may be interpreted by the onset of dormancy break and sprout formation which leads to starch break down, and sucrose synthesis. The slowing down in the rate of decline of reducing sugars corresponded to the time when the levels of sucrose content started to increase. These results are supported by the statements of Isherwood and Burton (1975) that an increase in the reducing sugars occurred after storing untreated tubers for prolong storage times.

5.4 The sprout inhibitor (C.I.P.C.) and temperature interaction

The chip color did not change significantly when tubers were stored at a specific temperature, whether treated with C.I.P.C. or not. The same is true for % reducing sugars and sucrose content levels. These results are in agreement with those of Khurana, *et al.* (1985); Khurana and Randhawa, (1985); Hughes and Fuller, (1984); Schippers (1975) and Zaehring *et al.* (1966).

5.5 Regression analysis of the three variables on storage duration

The potato tubers stored at 6°C, treated with C.I.P.C or not, produced chips of similar values at the end of the storage period. The rate of improvement in chip color continued to rise until the end of the storage period. The difference between the rate of improvement in chip color, whether the tuber were treated with C.I.P.C. or not and stored at

9°C is not significant. The treated tubers continued to produce lighter chip color. The untreated tubers slowed down in the rate of chip color improvement after storing the tubers for eight weeks, then the chip color value remained unchanged until the end of the storage period. The treated and untreated tubers stored at 12°C, produced chips of similar value from the beginning of the storage period until the end. But the rate of color improvement slowed down after storing the tubers for eight weeks until the end of the storage period, (Figure 5). The variations in the chip color explained by storage duration at the different levels of C.I.P.C. and temperature interactions are not consistent.

The treated and untreated tubers stored at 6°C, contained initially different levels of % reducing sugars. The rate of decline in the % reducing sugars continued go down sharply in the treated tubers until the end of the storage period, since the treated tubers contained much higher levels of % reducing sugars. The rate of decline in % reducing sugars in untreated tubers was less sharp and continuous.

The treated and untreated tubers stored at 9°C, contained similar amounts of % reducing sugars, and the rate of decline of the % reducing sugars was the same for both until the end of the storage period. The rate of decline slowed down after storing the potatoes for eight weeks and continued to slow down until the end of the storage period.

When treated and untreated tubers stored at 12°C, both contained equal amounts of % reducing sugars until after storing tubers for four weeks. The rate of decline of % reducing sugars started to alter in both treated and untreated tubers together until the seventh week of storage, then levelled off. The % reducing sugars started to increase after eight weeks of storage until the end of the storage period. The rate of decline in % reducing sugars in the treated tubers started to slow down after seven weeks of storage to the seventh week. The % reducing sugars level did not change after nine weeks of storage. The variations in % reducing sugars due to storage duration at different levels of C.I.P.C. and temperature interactions is not consistent.

The treated and untreated tubers stored at 6°C contained different levels of sucrose initially, and the rate of decline in the sucrose content for both was different. In treated tubers, the rate of decline of sucrose content was sharp for the first seven weeks of storage duration, then it slowed down until after eight weeks of storage. The level started to increase again after eight weeks until the end of the storage duration. The level of sucrose content in untreated tubers declined at a slower rate, and the rate slowed down further after seven weeks of storage until the end of the storage period. When tubers were stored at 9°C, whether treated with C.I.P.C. or not, the rate of decline in the level of sucrose content was similar. The rate of decline slowed down after seven weeks of storage, then it levelled off for one week. The sucrose level started to rise again after eight weeks of storage period until the end of the storage period.

Treated and untreated tubers stored at 12°C, contained different levels of sucrose and the sucrose level declined at a similar rate for both treated and untreated tubers. The rate of decline slowed down until seven weeks of storage period then it levelled off for one week. The sucrose level started to increase again after storing potatoes for eight weeks until the end of the storage period, (Figure 7).

5.6 Correlation of chip color to other quality parameters and storage duration

The relationship between the chip color and the other two quality parameters, % reducing sugars and sucrose content (in this study) exhibited a significant correlation. The chip color changes relate stronger to changes in % reducing sugars than to changes in sucrose contents, since the reducing sugars directly contributes to darkening of the chip colors. The signs of the coefficients indicate that increased levels of % reducing sugars and sucrose content corresponds to lower chip color scores (darker chips) and vice versa. The results of these investigations are in agreement with those of Mazza, (1983).

Highest correlation coefficient in magnitude between chip color and % reducing sugars are exhibited at the highest temperature (12°C) in this study. The next highest correlation is at

9°C and the third in magnitude is at 6°C.

The C.I.P.C. application did not affect significantly on the magnitude of these correlation. The storage temperature of 9°C contributed to the highest correlation between chip color and sucrose content. Again C.I.P.C. applications did not affect the magnitude of these correlations significantly.

8 The storage temperature of 9°C contributed to the highest correlation between chip color and storage duration. C.I.P.C. did not exert a significant effect on the correlations between chip color and the storage duration.

6. SUMMARY AND CONCLUSIONS

It is concluded from the results of this study that the chip color of the Norchip potato cultivar was the lightest when the tubers were stored at 12°C for ten weeks. The % reducing sugars and the sucrose content declined to their lowest at 12°C.

It is also concluded that C.I.P.C. influenced the color of the chips significantly. The chip color value was lower when the tubers were treated with C.I.P.C.. The % reducing sugars and sucrose content values did not change significantly whether tubers were treated with C.I.P.C. or not. C.I.P.C. and temperature interactions did not influence the value of any of the parameters measured.

It is concluded from the results of the regression polynomial analysis that the sucrose content started to rise after seven weeks of storage when the potatoes were stored at 9 and 12°C, and continued to rise until the end of the storage period (week 10), whether tubers were treated with C.I.P.C. or not. The sucrose content started to rise after eight weeks of storage at 6°C and continued to rise until the end of the storage period. This result also occurred whether tubers were treated with C.I.P.C. or not.

The % reducing sugars started to rise after nine weeks of storage at 12°C. The rise in % reducing sugars was less when potatoes were treated with C.I.P.C.. The % reducing sugars continued to decline when tubers were stored at 9 and 12°C until the end of the storage period (week 10). When the tubers were stored at 9°C, the decline in % reducing sugars levelled off between week 9 and 10 of storage duration, whether tubers were treated with C.I.P.C. or not.

It is concluded from the results of this study that sucrose content started to increase after prolonged storage duration at 9 and 12°C. The change in % reducing sugars followed the change in sucrose content. The change in chip color values corresponded to the changes in % reducing sugars. This may be interpreted that chip color values correspond to % reducing sugars changes which correspond to sucrose content changes.

It is also concluded from the results of this study that the correlation between chip color and % reducing sugar is stronger than the correlation between chip color and sucrose. As the level of % reducing sugars and sucrose increases the chip color becomes darker.

Generally, the results of this study are in agreement with the results of previous investigators. According to this study, the best temperature to store potatoes for chip making is at 9 and 12°C without C.I.P.C. applications. More research is needed to investigate the effect of various storage temperatures and prolonged storage duration with and without C.I.P.C. on the quality of the processed potatoes.

7. LITERATURE CITED

- Agle, William, M., and G.W. Woodbury. 1968. Specific gravity - dry matter relationship and reducing sugar changes affected by potato variety, production area and storage. *Am. Pot. J.* 45: 119-131.
- Anonymous, 1985. Pacific North West(PNW). Extension publication. J.O. Young (ed). Washington State University.
- Ashoor, S.H., and J.B. Zent. 1984. Maillard browning of common amino acids and sugars. A research note. *J. Food Sci.* 49: 1206-1207.
- Bishop, C.F.H., W.F. Maunder, 1980. Potato storage. (I) Ventillation *In: Potato Mechanisation and Storage*. Farming Press Ltd. Wharfedale Road, Ipswich, Suffolk. pp 170-195.
- Bishop, J.C., and V.H. Schweers. 1961. Sprout inhibition of fall-grown potatoes by airplane applications of maleic hydrazide. *Am. Pot. J.* 38: 377-381.
- Booth, R.H., and R.L. Shaw. 1981. Principles of potato storage. *Intl. Pot. Ctr. Apartado 5959, Lima, Peru.* pp 15-23.
- Buitelaar, N. 1981. Sprout inhibition in ware potato storage. *In: Storage of potatoes. Post-harvest behavior, store design, storage practice, handling*. Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for Agricultural publishing and documentation. Wageningen. pp 344-356.
- Burton, W.G., and A.R. Wilson. 1978. The sugar content and sprout growth of tubers of potato cultivar Record, grown in different localities, when stored at 10, 2 and 20°C. *Pot. Res.* 21: 145-162.
- Burton, W.G. 1977. Senescence in stored potatoes. *Proc. of the Assoc. of Appl. Biol. Annals Appl. Biol.* 85: 433-436.
- Burton, W.G. 1975. The immediate effect of gamma-irradiation upon the sugar content of potatoes previously stored at 2, 4.5, 6, 10 and 15.5°C. *Pot. Res.* 18: 109-115.

- Burton, W.G. 1969. The sugar balance in some British potato varieties during storage. II. The effects of tuber age, previous storage temperature, and intermittent refrigeration upon low-temperature sweetening. *Eur. Pot. J.* 12: 81-95.
- Burton, H. and N.V. Zonen W.G. 1966. *The potato*. 2nd Ed. Veenman, Wageningen.
- Burton, W.G. 1965. The sugar balance in some British potato varieties during storage. I. Preliminary observations. *Eur. Pot. J.* 2: 105-116.
- Burton, W.G., and R.S. Hannan. 1957. Use of γ radiation for preventing the sprouting of potatoes. *J. Sci. of Food and Agric.* 12:707-715.
- Carlsson, H. 1970. Production of potatoes for chipping. *Plant Husbandry. Vaxtodling. Almqvist & Wiksells Boktryckerii Ab. Uppsala.* pp 9-64.
- Clegg, M.D., and H.W. Chapman. 1962. Post harvest discoloration of chips from early summer potatoes. *Am. Pot. J.* 39: 176-184.
- Clegg, M.D., and H.W. Chapman. 1962. Sucrose content of tubers and discoloration of chips from early summer potatoes. *Am. Pot. J.* 39: 212-216.
- Corsini, D., G. Stallknecht, and W. Sparks. 1979. Changes in chlorpropham residues in stored potatoes. *Am. Pot. J.* 56: 43-50.
- Cotter, D.J., and R.L. Sawyer. 1961. The effect of gamma irradiation on the incidence of Black spot, and ascorbic acid, glutathione and tyrosinase content of potato tubers. *Am. Pot. J.* 38: 59-65.
- Cunningham, H.H., M.V. Zaehring, and W.C. Sparks. 1971. Storage temperature for maintenance of internal quality in Idaho Russet Burbank potatoes. *Am. Pot. J.* 48: 320-328.
- Cunningham, C.E., and F.J. Stevenson. 1963. Inheritance of factors affecting potato chip color and their association with specific gravity. *Am. Pot. J.* 40: 253-265.
- Dahlenburg, A.P. 1982. Prediction of darkening in potatoes during frying. *Food Tech. in Aust.* 34: 544-547.

Dalziel, J., T.C. Altchison, and H.J. Duncan. 1980. Studies on potato sprout suppressants. 3.

Effect of storage conditions on tecnazene residue levels in treated tubers. *Pot. Res.*

23: 335-344.

Davis, R.M., Jr. 1961. Ingrown sprouts in potato tubers: factors accompanying their origin in Ohio. *Am. Pot. J.* 38: 411-413.

De Man, J.M. 1980. Non-enzymatic browning. *In: Principles of Food Chemistry*. The Avi.

Publ. Co., Westport, CT. pp 98-134.

Dwelle, R.B., and G.F. Stallknecht. 1978. Respiration and sugar content of potato tubers as influenced by storage temperature. *Am. Pot. J.* 55: 561-571.

Es, A. Van, and K.J. Hartmans. 1981. Dormancy period, sprouting and sprout inhibition. *In: storage of potatoes. Post-harvest behavior, store design, storage practice, handling*, Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for Agriculture publishing and documentation. Wageningen. pp 99-119.

Es, Van A., and K.J. Hartmans. 1981. Sugars and starch during tuberization and sprouting. *In: Storage of potatoes. Post-harvest behavior, store design, store practice, handling*. Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for Agricultural Publishing and Documentation. Wageningen. pp 82-98.

Filmer, A.A.E., and M.J.C. Rhodes. 1984. An assessment of 1, 4, 6,-trimethylnaphthalene as a sprout suppressant for stored potato tubers. *Pot. Res.* 27: 383-392.

Franklin, E.W., and N.R. Thompson. 1953. Some effects of maleic hydrazide on stored potatoes. *Am. Pot. J.* 30: 289-295.

Habib, A.T., and H.D. Brown. 1957. Role of reducing sugars and amino acids in the browning of potato chips. *Food Technol.* 2: 85-89.

Habib, A.T., and H.D. Brown. 1956. Factors influencing the color of potato chips. *Food Tech.* 10: 332-336.

- Hruschka, H.W., and P.H. Heinze. 1967. External and internal sprouts in potatoes dipped in low concentration C.I.P.C.-water emulsions. *Am. Pot. J.* 44: 51-55.
- Hruschka, H.W., P.C. Marth and P.H. Heinze, 1965. External sprout inhibition and internal sprouts in potatoes. *Am. Pot. J.* 42: 209-222.
- Hughes, J.C., and T.J. Fuller. 1984. Fluctuation in sugars in cv. Record during extended storage at 10°C. *Pot. Res.* 27: 229-236.
- Hyde, R.B., and J.W. Morrison. 1964. The effect of storage temperature on reducing sugars, pH, and phosphorylase enzyme activity in potato tubers. *Am. Pot. J.* 41: 161-168.
- Isherwood, F.A. 1976. Mechanism of starch-sugar interconversion in *Solanum tuberosum*. *Phytochem.* 15: 33-41.
- Isherwood, F.A., and W.G. Burton. 1975. The effect of senescence, handling, sprouting and chemical sprout suppression upon respiratory quotient of stored potato tubers. *Pot. Res.* 18: 98-104.
- Isherwood, F.A. 1973. Starch-sugar interconversion in *Solanum tuberosum*. *Phytochem.* 12: 2579-2591.
- Ivens, G.W. and Blackman, G.F. 1949. The effect of phenylcarbamates on the growth of higher plants. In: selective toxicity and antibiotics. Symposia of Soc. for Exper. Biol. Acad press. pp 266-282.
- Kennedy, E.J., and O. Smith. 1953. Response of seven varieties of potatoes to foliar applications of maleic hydrazide. *Proc. Am. Soc. Hort. Sci.* 61: 395-403.
- Khurana, D.S., and K.S. Randhawa. 1985. Yield and quality of dehydrated chips prepared from sprout inhibitor treated potatoes stored under different conditions. *J. of Food Sci. & Tech.* 22: 433-436.
- Khurana, D.S., K.S. Randhawa, and K.L. Bajaj. 1985. Carbohydrate content of potato (*Solanum tuberosum* L.) tubers treated with Isopropyl-N(3-chlorophenyl) Carbamate under different storage conditions. *J. Sci. Food Agric.* 36: 959-962.

- Kim, M.S.L., E.E. Ewing, and J.B. Siezeka. 1972. Effects of chlorpropham (C.I.P.C.) on sprouting of individual potato eyes and on plant emergence. *Am. Pot. J.* 49: 420-430.
- Leach, S.S. 1978. Quality stored potatoes improved by chemical treatment. *Am. Pot.-J.* 55: 155-159.
- Marquez, G. and M.C. Anon. 1986 Influence of reducing sugars and amino acids in the color development of fried potatoes. *J. Food Sci.* 51(1): 157-160.
- Mazza, G. 1983 Correlation between quality parameters of potato during growth and long-term storage. *Am. Pot. J.* 60: 145-159.
- Mazza, G. J. Hung and M.J. Dench, 1983. Processing/Nutritional Quality changes in potato tubers during growth and long-term storage. *Can. Inst. Food Sci Tech. J.* 16(1): 39-44.
- Meigh, D.F., A.A.E. Filmer, and R. Self. 1973. Growth-inhibitory volatile aromatic compounds produced by *Solanum tuberosum*. *Phytochem.* 12: 987-993.
- Meijers, C.P. 1981. Wound healing. In: storage of potatoes. Post-harvest behavior, store design, storage practice, handling. Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for Agricultural publishing and documentation. Wageningen. pp 340-343.
- Miller, R.A., J.D. Hamington, and G.D. Kuhn. 1975. Effect of variety and harvest date on tuber sugars and chip color. *Am. pot. J.* 52: 379-386.
- Mondy, N.I., P. Klein, and L.I. Smith. 1960. Effect of maturity and storage on phenolic content, enzymic activity, and discoloration of potatoes. *Food Res* 265: 693-705.
- Mondy, N.I., S.B., Gedde-Dahl, and E.O. Mobley. 1966a. Relation of specific gravity to the enzymic activity and phenolic content of potatoes. *J. Food Sci.* 31: 157-160.
- Mondy, N.I., S.B. Gedde-Dahl, and E.O. Mobley. 1966b. Effect of storage temperature on the cytochrome oxidase and polyphenol oxidase activities and phenolic content of potatoes. *J. Food Sci.* 31: 32-37.
- Nelson, D.C., and J.R. Sowokinos. 1983. Yield and relationships among tuber size, sucrose and chip color in six potato cultivars on various harvest dates. *Am. Pot. J.* 60: 949-958.

- Nelson, D.C., and R. Shaw. 1976. Effect of planting and harvest dates, location in the hill and tuber size on sugar content of Kennebec potatoes. *Am. Pot. J.* 43: 14.
- Nylund, R.E., and L.C. Ayres. 1964. Sprout inhibition of table stock potatoes with C.I.P.C.-treated paper bags. *Am. Pot. J.* 41: 341-348.
- Ohad, I., I. Friedberg, Z. Neeman, and M. Schram. 1971. Biogenesis and degradation of starch. I. The fate of the amyloplast membranes during maturation and storage of potato tubers. *Plant Physiol.* 47: 465-477.
- Ponnampalam, R. and N.I. Mondy. 1986. Effect of sprout inhibitor Isopropyl N-(3-chlorophenyl) carbamate (CIPC) on phenolic and ascorbic acid content of potatoes. *J. Agric. Food Chem.* 34: 262-263.
- Pressey, R. 1969. Role of invertase in the accumulation of sugars in cold stored potatoes. *Am. Pot. J.* 46: 291.
- Rastovski, A. 1981. Temperature control during storage. *In: Storage of potatoes. Post-harvest behavior, store design, storage practice, handling.* Rastovski, A., A. Van Es *et al.*. Pudoc. centre for agricultural publishing and documentation. Wageningen. pp 365-367.
- Rastovski, A. 1981. Storage conditions. *In: Storage of potatoes. Post-harvest behavior, store design, storage practice, handling.* Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for agricultural publishing and documentation. Wageningen. pp 173-174.
- Reeve, R.M., L.J. Forrester, and C.E. Handel. 1963. Histological analysis of wound healing in potatoes treated to inhibit sprouting. 1. C.I.P.C. (Isopropyl-N-3-chlorophenyl) carbamate treatments. *J. Food Sci.* 28: 649-654.
- Ross, A.G. 1975. Dinitrophenol method for reducing sugars. *In: potato processing.* 3rd ed., W.F. Talburt, and O. Smith (eds.). AVI Publ. Co., Inc., Westport, CT. pp 696-697.
- Samotus, B., and S. Schwimmer. 1962. Predominance of fructose accumulation in cold stored immature potato tubers. *J. Food Sci.* 27: 1-4.

- Sawyer, R.L., and S.L. Dallyn. 1961. Effect of irradiation on storage quality of potatoes. *Am. Pot. J.* 38: 227-235.
- Sawyer, R.L. 1961. Relation of chrolo-IPC for potato sprout inhibition to internal sprouting of potatoes. *Am. Pot. J.* 38: 203-207.
- Sawyer, R.L., and W.H. Thorne. 1962. Alcohols for sprout inhibition of potatoes. *Am. Pot. J.* 39: 167-175.
- Sawyer, R.L. and S.L. Dallyn. 1964. Internal sprouting of potatoes. *Am. pot. J.* 41: 59-69.
- Sawyer, R.L. 1975. Sprout inhibition. *In: Potato processing*. 3rd ed. W.F. Talburt and O. Smith (eds). The AVI Publ Comp. Inc., Westport, CT. pp 157-169.
- Schild, Van der, J.H.W. 1981. History of potato storage. *In: storage of potatoes. Post-harvest behavior, store design, storage practice, handling*. Rastovski, A., A. Van Es *et al.*. Pudoc. Centre for agricultural publishing and documentation. Wageningen. pp 3-13.
- Schippers, P.A. 1975. The influence of storage conditions on chip color of potatoes. *Pot. Res.* 18: 479-494.
- Shallenberger, R.S., O. Smith, and R.H. Treadway. 1959. Role of the sugars in the browning reaction in potato chips. *J. Agric. Food Chem.* 7: 274-277.
- Shekhar, V.C., and W.M. Iritani. 1978. Starch to sugar interconversion in *Solanum tuberosum* L. I. Influence of inorganic ions. *Am. Pot. J.* 55: 345-350.
- Smith, O. 1977. Potato processing. *In: Potatoes, production, storage, processing*. 2nd ed. The AVI Publ. Co. Inc., Westport, CT. pp 677-724
- Smith, O. 1977. Storage of potatoes. *In: Potatoes, production, storing, processing*. 2nd ed. The AVI Publ. Co. Inc., Westport, CT. pp 436-469.
- Smith, O. 1975. Effect of transit and storage conditions on potatoes. *In: Potato processing*. 3rd ed. W.F. Talburt and O. Smith (eds). The AVI Publ. Co. Inc., Westport, CT. pp 171-233.

- Smith, O. 1975. Potato chips. In: potato processing. 3rd ed. W.F. Talburt and O. Smith (eds). The AVI Publ Co Inc., Westport, CT. pp 305-402.
- Smith, O. 1975. Effect of cultural and environmental conditions on potatoes for processing. In: potato processing. 3rd ed. W.F. Talburt and O. Smith (eds). The AVI Publ. Co. Inc., Westport, CT. pp 67-125.
- Smith, O. 1967. Potato chip processing. In: Potato handbook. Revised potato processing Issue. Potato Assoc. Am. J. C. Campbell (ed). Rutgers Univ., New Brunswick, N.J. pp 46-53.
- Spark, A.A. 1969. Role of amino acids in non-enzymic browning. J. Sci. Food. Agric. 20(5): 308-316.
- Sowokinos, J.R. 1978. Relationship of harvest sucrose content to processing maturity and stotage life of potatoes. Am. Pot. J. 55: 333-343.
- Sowokinos, J.R. 1973. Maturation of *Solanum tuberosum*. I. Comparative sucrose and sucrose synthetase levels between several good and poor processing varieties. Am. Pot. J. 50: 234-247.
- Steel, R.G.D., J.H. Torrie. 1980. Principles and procedures of statistics. A biometric approach. 2nd ed. McGraw Hill Book Company. pp 597.
- Stevenson, F.J., C.E, Cunningham. 1961. Chip color in relation to potato storage. Am. Pot. J. 38: 105-113.
- Thornton, R.E., J.B. Sieczka, 1980. Commercial potato production in North America. Potato Assoc. of America Handbook. Supplement to Vol. 57 of the Am. Pot. J. Revision of U.S.D.A. Agric. Handbook 267. By the Extension Committee of the Potato Assoc. of Amer. pp 34-36.
- Van Handel, E. 1968. Direct microdetermination of sucrose. Anal. Biochem. 22: 280-283.
- Van Vliet, W.F., and H. Sparenberg. 1970. The treatment of potato tubers with sprout inhibitors. Pot. Res. 13: 223-227.

- Van Vliet, W.F., and W.H. Schriemer. 1963. High temperature storage of potatoes with the aid of sprout inhibitors. 3(6): 201-219.
- Verma, S.C., T.R. Sharma, and S.M. Varma. 1974a. Sucrose accumulation during high-temperature storage of potato tubers. *Pot. Res.* 17: 224-226.
- Verma, S.C., T.R. Sharma, and S.M. Varma. 1974b. Effects of extended high temperature storage on weight losses and sugar content of potato tubers. *Indian J. Agric. Sci.* 44(11): 702-706.
- Weis, G.G., J.A. Schoenemann, and M.D. Groskopp. 1980. Influence of time of application of maleic hydrazide on the yield and quality of Russet Burbank potatoes. *Am. Pot. J.* 57: 197-204.
- Wilson, A.M., Bushway, A.A. and Bushway R.J. 1981. Residue analysis of isopropyl-N-(3-chlorophenyl) carbamate in fruits and vegetables using high-performance liquid chromatography. *J. Agric. Food Chem.* 29: 746-749.
- Wilson, D. 1985. PPG Industries Canada Ltd, Stanchem Div. Personal communication.
- Work, T.M., A.S. Kezis, and R.H. True. 1981. Factors determining potato chipping quality. *Tech. Bull.* 103. *Life Sci. Agric. Expt. St., Univ. of Maine at Orono*, pp 1-28.
- Yamaguchi, M. 1959. Effect of certain areas of production and storage on chipping quality, chemical composition and specific gravity of California potatoes. *Proc. Am. Soc. Hort. Sci.* 74: 649-660.
- Zaehring, V.M., H.H. Cunningham, and C.W. Sparks. 1966. Sugar content and color of Russet Burbank potatoes as related to storage temperature and sprout inhibitors. *Am. Pot. J.* 43: 305-314.
- Zaehring, M.V. R.M. Reeve, E.A. Talley, D.H. Dinkel and R.B. Hyde. 1967. Specific gravity and composition of potatoes for various processing and cooking purposes. In: *potato Handbook, Revised potato processing Issue*. Potato Assoc. Am. J.C. Campbell (ed). Rutgers Univ., New Brunswick, N.J. pp 5-11.

8. APPENDIX TABLES

8.1 Appendix 1. Analysis of variance of chip color.

Source of variation	df	Sum of squares	Mean square	F-test	Probability
Storage duration (D)	9	15325.139	1702.794	105.690	0.001
R within D	20	322.222	16.111	2.028	0.12
C.I.P.C. (C)	1	50.139	50.139	6.311	0.014
C by D	9	179.250	19.583	2.465	0.014
Temperature (T)	2	9216.944	4608.472	580.087	0.001
T by D	18	1363.611	75.756	9.536	0.001
T by C	2	38.611	19.306	2.430	0.093
T by C by D	18	164.167	9.120	1.148	0.319
Residual	100	794.444	7.944		

8.2 Appendix 2. Analysis of variance of % reducing sugars

Source of variation	df	Sum of squares	Mean square	F-test	Probability
Storage duration(D)	9	7.740	0.860	76.64	0.001
R within D	20	0.224	0.011	1.224	0.251
C.I.P.C. (C)	1	0.021	0.021	2.332	0.130
C by D	9	0.150	0.017	1.816	0.074
Temperature (T)	2	3.505	1.752	191.120	0.001
T by D	18	0.456	0.025	2.761	0.001
T by C	2	0.012	0.006	0.637	0.531
T by C by D	18	0.274	0.152	1.661	0.060
Residual	100	0.917	0.009		

8.3 Appendix 3. Analysis of variance of sucrose content.

Source of variation	df	Sum of squares	Mean squares	F-test	Probability
Storage duration(D)	9	655.55	72.839	56.749	0.001
R within D	20	25.671	1.284	0.471	0.972
C.I.P.C. (C)	1	0.834	0.834	0.031	0.861
C by D	9	20.136	2.237	0.821	0.598
Temperature (T)	2	224.201	147.100	53.987	0.001
T by D	18	32.491	1.805	0.662	0.840
T by C	2	7.002	3.501	1.285	0.281
T by C by D	18	41.902	2.328	0.854	0.633
Residual	100	272.475	2.725		

8.4 Appendix 4. Treatment means of chip color, % reducing sugars and sucrose content for (C.I.P.C.) and temperature combinations.

Treatments	Chip Color (U.S.D.A. Standard)	Reducing sugar %	Sucrose content (mg/g f w)
No C.I.P.C., 6°C	29	0.726	5.549
No C.I.P.C., 9°C	40	0.500	3.063
No C.I.P.C., 12°C	46	0.399	2.050
C.I.P.C., 6°C	29	0.748	5.105
C.I.P.C., 9°C	39	0.541	3.114
C.I.P.C., 12°C	46	0.401	2.572
SEM	0.483	0.020	0.277
Probability	0.093	0.531	0.281